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TECHNICAL REPORT RD-80-2

CALCULATION OF THE LAMINAR VISCOSITY OF A GASEOUS MIXTURE FOR GAS DYNAMIC MIXING COMPARISONS FOR A REACTING SHEAR LAYER

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October 1979

U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35809

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This investigation determined the laminar viscosities of NO_2 and O_3 at elevated temperatures. The technique to accomplish this is relevant to other gases and a generalized method for calculation of viscosities of other gases is presented. The results are compared to the calculational method of Svehla {2} for CO_2 at elevated temperatures. A cubic spline interpolation routine using a Lagrangian polynomial treatment of the end points is formulated and coded.

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TABLES

I. INTRODUCTION

In the process of evaluating various turbulent mixing models, the question kept arising of how the turbulent flow differed from the laminar flow. A comparison of two different turbulence kinetic energy models is given in Walker [4] and, in addition, the use of a laminar viscosity model for comparison with the turbulence models is discussed. This was accomplished for a reacting shear layer for which experimental results had been obtained. Therefore, the techniques and results presented herein were utilized to make qualitative comparisons.

Additionally the techniques presented in this work are directly useful in the chemical laser program because of the fine scale mixing in the nozzles and the low pressure operation in the laser cavity. The coding presented herein is applicable only for a N_2, O_2, NO, NO_2, and O_3 system but minor coding changes will make these results applicable for any gas at low pressure.

II. CUBIC SPLINE INTERPOLATION

In order to determine the laminar viscosity of the various gases involved as a function of temperature, it is necessary to interpolation *Table 1* for temperatures not given. This could be done utilizing a simple linear interpolation scheme. However, a more accurate scheme which does not take an excessive amount of computational time is cubic spline interpolation. This is a piecewise cubic interpolation scheme that matches the function and its slope at each of the known points given in *Table 1*. Cubic spline interpolation is currently very popular and will be utilized here.

The only problem with this scheme occurs at the end points of the interval. The requirement that the slopes be matched at this point between the piecewise cubic sections cannot be met since no other point is available from which to calculate the slope. Therefore a special treatment for the end points was necessary and the use of a Lagrangian polynomial was chosen.

The Lagrangian polynomial is given by

$$p(x) = \sum_{k=o}^{n} f(x_k)\ l_k(x) \tag{1}$$

TABLE 1. FUNCTIONS FOR PREDICTION OF TRANSPORT PROPERTIES OF GASES AT LOW DENSITIES [3]

$\kappa T/\epsilon$	Ω_μ	$\kappa T/\epsilon$	Ω_μ	$\kappa T/\epsilon$	Ω_μ	$\kappa T/\epsilon$	Ω_μ
		1.25	1.424	2.50	1.093	4.50	0.9464
0.30	2.785	1.30	1.399	2.60	1.081	4.60	0.9422
0.35	2.628	1.35	1.375	2.70	1.069	4.70	0.9382
0.40	2.492	1.40	1.353	2.80	1.058	4.80	0.9343
0.45	2.368	1.45	1.333	2.90	1.048	4.90	0.9305
0.50	2.257	1.50	1.314	3.00	1.039	5.0	0.9269
0.55	2.156	1.55	1.296	3.10	1.030	6.0	0.8963
0.60	2.065	1.60	1.279	3.20	1.022	7.0	0.8727
0.65	1.982	1.65	1.264	3.30	1.014	8.0	0.8538
0.70	1.908	1.70	1.248	3.40	1.007	9.0	0.8379
0.75	1.841	1.75	1.234	3.50	0.9999	10.0	0.8242
0.80	1.780	1.80	1.221	3.60	0.9932	20.0	0.7432
0.85	1.725	1.85	1.209	3.70	0.9870	30.0	0.7005
0.90	1.675	1.90	1.197	3.80	0.9811	40.0	0.6718
0.95	1.629	1.95	1.186	3.90	0.9755	50.0	0.6504
1.00	1.587	2.00	1.175	4.00	0.9700	60.0	0.6335
1.05	1.549	2.10	1.156	4.10	0.9649	70.0	0.6194
1.10	1.514	2.20	1.138	4.20	0.9600	80.0	0.6076
1.15	1.482	2.30	1.122	4.30	0.9553	90.0	0.5973
1.20	1.452	2.40	1.107	4.40	0.9507	100.0	0.5882

where

$$l_k(x) = \frac{g_k(x)}{g_k(x_k)} \prod_{\substack{i=o \\ i \neq k}}^{n} \frac{(x - x_i)}{x_k - x_i} \qquad (2)$$

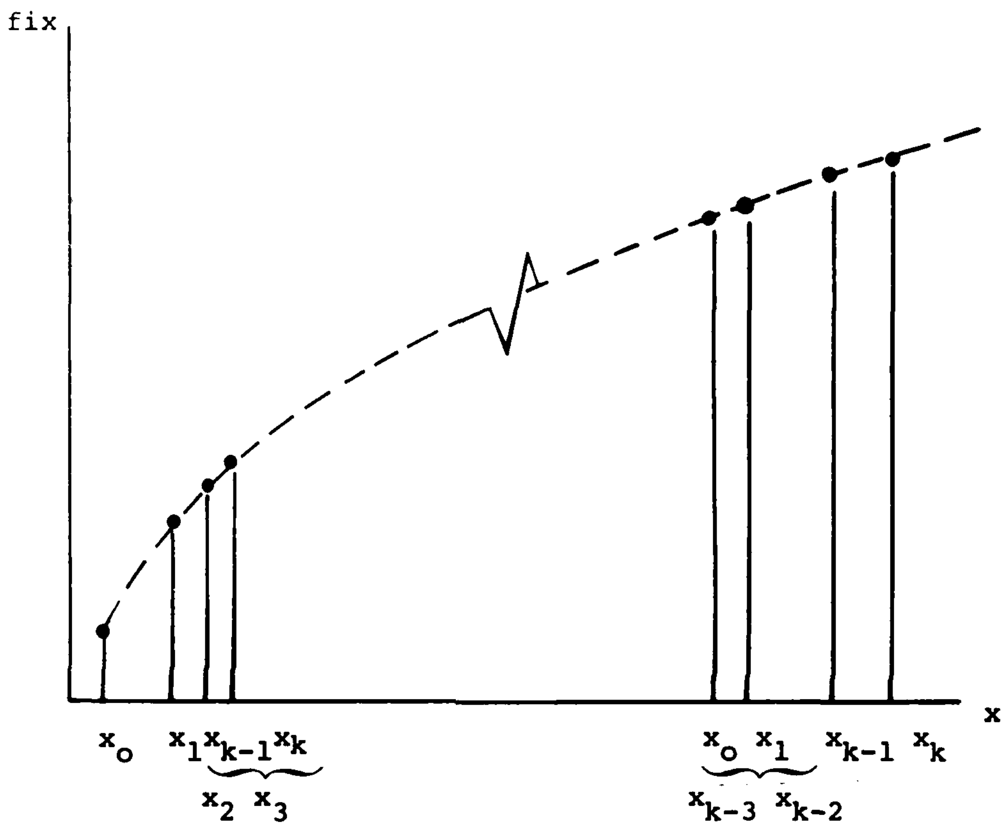

Figure 1. End points nomenclature.

For the end points shown.

$$p(x) = f(x_o)l_o(x) + f(x_1)l_1(x) + f(x_{k-1})l_{k-1}(x) + f(x_k)l_k(x) \qquad (3)$$

$$l_o(x) = \left\{\frac{x - x_1}{x_o - x_1}\right\}\left\{\frac{x - x_{k-1}}{x_o - x_{k-1}}\right\}\left\{\frac{x - x_k}{x_o - x_k}\right\}$$

$$l_1(x) = \left\{\frac{x - x_o}{x_1 - x_0}\right\}\left\{\frac{x - x_{k-1}}{x_1 - x_{k-1}}\right\}\left\{\frac{x - x_k}{x_1 - x_k}\right\}$$

$$l_{k-1}(x) = \left\{\frac{x - x_o}{x_{k-1} - x_o}\right\}\left\{\frac{x - x_1}{x_{k-1} - x_1}\right\}\left\{\frac{x - x_k}{x_{k-1} - x_k}\right\} \tag{4}$$

$$l_k(x) = \left\{\frac{x - x_o}{x_k - x_o}\right\}\left\{\frac{x - x_1}{x_k - x_1}\right\}\left\{\frac{x - x_{k-1}}{x_k - x_{k-1}}\right\}$$

Now

$$f(x_k) = \text{const}$$

$$x_k - x_i = \text{const}$$

hence

$$\frac{dp(x)}{dx} = f(x_o)\,l_o'(x) + f(x_1)\,l_1'(x) + f(x_{k-1})\,l_{k-1}'(x) + f(x_k)\,l_k'(x) . \tag{5}$$

Now

$$l_o(x) = \frac{1}{(x_o - x_1)(x_o - x_{k-1})(x_o - x_k)} *$$

$$\left\{(x - x_1)(x - x_{k-1})(x - x_k)\right\}$$

hence

$$l_o'(x) = (x - x_1) \frac{d}{dx} (x^2 - xx_{k-1} - xx_k + x_{k-1}x_k)*$$

$$\left\{\frac{1}{(x_o - x_1)(x_o - x_{k-1})(x_o - x_k)}\right\} + (x - x_{k-1})(x - x_k)*$$

$$\left\{\frac{1}{(x_o - x_1)(x_o - x_{k-1})(x_o - x_k)}\right\}$$

$$l_o'(x) = \frac{1}{(x_o - x_1)(x_o - x_{k-1})(x_o - x_k)}$$

$$\left[(x - x_1)(2x - x_{k-1} - x_k) + (x - x_{k-1})(x - x_k)\right]$$

and

$$\boxed{l_o'(x) = \frac{(x - x_1)(2x - x_{k-1} - x_k) + (x - x_{k-1})(x - x_k)}{(x_o - x_1)(x_o - x_{k-1})(x_o - x_k)}} \quad (6)$$

$$l_1(x) = \frac{1}{x_1 - x_o)(x_1 - x_{k-1})(x_1 - x_k)}*$$

$$\left\{(x - x_o)(x - x_{k-1})(x - x_k)\right\}$$

$$l_1'(x) = \frac{1}{(x_1 - x_o)(x_1 - x_{k-1})(x_1 - x_k}\left[(x - x_o)\right.$$

$$\left.\frac{d}{dx}\left\{x^2 - xx_{k-1} - xx_k + x_k x_{k-1}\right\} + (x - x_{k-1})(x - x_k)\right]$$

$$l_1'(x) = \frac{1}{(x_1 - x_o)(x_1 - x_{k-1})(x_1 - x_k)} \Big[(x - x_o)$$

$$\left\{2x - x_{k-1} - x_k\right\} + (x - x_{k-1})(x - x_k) \Big]$$

$$\boxed{l_1'(x) = \frac{(x - x_o)(2x - x_{k-1} - x_k) + (x - x_{k-1})(x - x_k)}{(x_1 - x_o)(x_1 - x_{k-1})(x_1 - x_k)}} \qquad (7)$$

$$l_{k-1}(x) = \frac{1}{(x_{k-1} - x_o)(x_{k-1} - x_1)(x_{k-1} - x_k)} \Big[(x - x_o)$$

$$(x - x_1)(x - x_k) \Big]$$

$$l_{k-1}'(x) = \frac{1}{(x_{k-1} - x_o)(x_{k-1} - x_1)(x_{k-1} - x_k)} \Big[(x - x_o)$$

$$\frac{d}{dx} \left\{x^2 - x_1 x - x_k x + x_1 x_k\right\} + (x - x_1)(x - x_k) \Big]$$

$$l_{k-1}'(x) = \frac{1}{(x_{k-1} - x_o)(x_{k-1} - x_1)(x_{k-1} - x_k)} \Big[(x - x_o)$$

$$(2x - x_1 - x_k) + (x - x_1)(x - x_k) \Big]$$

$$\boxed{l_{k-1}'(x) = \frac{(x - x_o)(2x - x_1 - x_k) + (x - x_1)(x - x_k)}{(x_{k-1} - x_o)(x_{k-1} - x_1)(x_{k-1} - x_k)}} \qquad (8)$$

$$l_k(x) = \frac{1}{(x_k - x_o)(x_k - x_1)(x_k - x_{k-1})} \Big[(x - x_o)$$

$$(x - x_1)(x - x_{k-1}) \Big]$$

$$l_k'(x) = \frac{1}{(x_k - x_o)(x_k - x_1)(x_k - x_{k-1})}\left[(x - x_o)\right.$$

$$\left.\frac{d}{dx}\left\{x^2 - xx_1 - xx_{k-1} + x_1\, x_{k-1}\right\} + (x - x_1)(x - x_{k-1})\right]$$

$$l_k'(x) = \frac{1}{(x_k - x_o)(x_k - x_1)(x_k - x_{k-1})}\left[(x - x_o)\right.$$

$$\left.(2x - x_1 - x_{k-1}) + (x - x_1)(x - x_{k-1})\right]$$

$$\boxed{l_k'(x) = \frac{(x - x_o)(2x - x_1 - x_{k-1}) + (x - x_1)(x - x_{k-1})}{(x_k - x_o)(x_k - x_1)(x_k - x_{k-1})}} \quad (9)$$

Hence the end point slopes are given by:

$$\frac{df(x)}{dx} = f(x_o)l_o'(x) + f(x_1)l_1'(x) + f(x_{k-1})l_{k-1}'(x)$$

$$+ f(x_k)\ l_k'(x) \quad (10)$$

where:

$$l_o'(x) = \frac{(x - x_1)(2x - x_{k-1} - x_k) + (x - x_{k-1})(x - x_k)}{(x_o - x_1)(x_o - x_{k-1})(x_o - x_k)}$$

$$l_1'(x) = \frac{(x - x_o)(2x - x_{k-1} - x_k) + (x - x_{k-1})(x - x_k)}{(x_1 - x_o)(x_1 - x_{k-1})(x_1 - x_k)}$$

$$l_{k-1}'(x) = \frac{(x - x_o)(2x - x_1 - x_k) + (x - x_1)(x - x_k)}{(x_{k-1} - x_o)(x_{k-1} - x_1)(x_{k-1} - x_k)}$$

$$l_k'(x) = \frac{(x - x_o)(2x - x_1 - x_{k-1}) + (x - x_1)(x - x_{k-1})}{(x_k - x_o)(x_k - x_1)(x_k - x_{k-1})}$$

Now when these equations are used to calculate the left end point slope

x_{k-1} Becomes x_2

x_k Becomes x_3

and when they are used to calculate the right end point slope

x_o Becomes x_{k-3}

x_1 Becomes x_{k-2}

as shown in *Figure 1*.

The special end point treatment was incorporated with a cubic spline interpolation routine developed by Conte and de Boor [1]. The program listing is given in Appendix A. As a test for this generalized routine, the viscosity function Ω_μ was interpolated at several points including input points to determine how well the cubic spline interpolation program was working. *Table 1* gives the known input data for Ω_μ as a function of $\kappa T/\epsilon$.

The results of the use of the cubic spline interpolation program are given in *Table 2*. Note that the interpolation scheme gives very smooth results. Also note that the input data is under no restriction as to the regularity of the input function interval i.e., $\Delta(\kappa T/\epsilon)$ varies from 0.05-5.0.

III. MOLECULAR VISCOSITY OF NO_2 AND O_3

The reacting shear layer that calculations were made for contained the following reaction:

$$NO + O_3 \rightarrow NO_2 + O_2$$

Since the mixed stream includes a combination of these gases, it is necessary to know the laminar viscosities of each of the component gases as a function of temperature. These have

TABLE 2. RESULTS OF CUBIC SPLINE INTERPOLATION ROUTINE FOR Ω_{μ} $(\kappa T/\epsilon)$ GIVEN IN TABLE 1.

PT.NO.=	1	X=	.30000000E+00	F(X)=	.27850000E+01
PT.NO.=	2	X=	.31000000E+00	F(X)=	.27514605E+01
PT.NO.=	3	X=	.32000000E+00	F(X)=	.27190614E+01
PT.NO.=	4	X=	.33000000E+00	F(X)=	.26877421E+01
PT.NO.=	5	X=	.34000000E+00	F(X)=	.26574019E+01
PT.NO.=	6	X=	.35000000E+00	F(X)=	.26280000E+01
PT.NO.=	7	X=	.36000000E+00	F(X)=	.25994682E+01
PT.NO.=	8	X=	.37000000E+00	F(X)=	.25717082E+01
PT.NO.=	9	X=	.38000000E+00	F(X)=	.25446140E+01
PT.NO.=	10	X=	.39000000E+00	F(X)=	.25180759E+01
PT.NO.=	11	X=	.40000000E+00	F(X)=	.24920000E+01
PT.NO.=	12	X=	.41000000E+00	F(X)=	.24662947E+01
PT.NO.=	13	X=	.42000000E+00	F(X)=	.24409899E+01
PT.NO.=	14	X=	.43000000E+00	F(X)=	.24161378E+01
PT.NO.=	15	X=	.44000000E+00	F(X)=	.23917946E+01
PT.NO.=	16	X=	.45000000E+00	F(X)=	.23680000E+01
PT.NO.=	17	X=	.46000000E+00	F(X)=	.23448009E+01
PT.NO.=	18	X=	.47000000E+00	F(X)=	.23221561E+01
PT.NO.=	19	X=	.48000000E+00	F(X)=	.23000108E+01
PT.NO.=	20	X=	.49000000E+00	F(X)=	.22763104E+01
PT.NO.=	21	X=	.50000000E+00	F(X)=	.22570000E+01
PT.NO.=	22	X=	.51000000E+00	F(X)=	.22360378E+01
PT.NO.=	23	X=	.52000000E+00	F(X)=	.22154338E+01
PT.NO.=	24	X=	.53000000E+00	F(X)=	.21952109E+01
PT.NO.=	25	X=	.54000000E+00	F(X)=	.21753920E+01
PT.NO.=	26	X=	.55000000E+00	F(X)=	.21560000E+01
PT.NO.=	27	X=	.56000000E+00	F(X)=	.21370479E+01
PT.NO.=	28	X=	.57000000E+00	F(X)=	.21185067E+01
PT.NO.=	29	X=	.58000000E+00	F(X)=	.21003466E+01
PT.NO.=	30	X=	.59000000E+00	F(X)=	.20825217E+01
PT.NO.=	31	X=	.60000000E+00	F(X)=	.20650000E+01
PT.NO.=	32	X=	.61000000E+00	F(X)=	.20477546E+01
PT.NO.=	33	X=	.62000000E+00	F(X)=	.20308037E+01
PT.NO.=	34	X=	.63000000E+00	F(X)=	.20141746E+01
PT.NO.=	35	X=	.64000000E+00	F(X)=	.19978973E+01
PT.NO.=	36	X=	.65000000E+00	F(X)=	.19820000E+01
PT.NO.=	37	X=	.66000000E+00	F(X)=	.19665017E+01
PT.NO.=	38	X=	.67000000E+00	F(X)=	.19513823E+01
PT.NO.=	39	X=	.68000000E+00	F(X)=	.19366121E+01
PT.NO.=	40	X=	.69000000E+00	F(X)=	.19221612E+01
PT.NO.=	41	X=	.70000000E+00	F(X)=	.19080000E+01
PT.NO.=	42	X=	.71000000E+00	F(X)=	.18941026E+01
PT.NO.=	43	X=	.72000000E+00	F(X)=	.18804595E+01
PT.NO.=	44	X=	.73000000E+00	F(X)=	.18670650E+01
PT.NO.=	45	X=	.74000000E+00	F(X)=	.18539137E+01
PT.NO.=	46	X=	.75000000E+00	F(X)=	.18410000E+01
PT.NO.=	47	X=	.76000000E+00	F(X)=	.18283199E+01
PT.NO.=	48	X=	.77000000E+00	F(X)=	.18158758E+01
PT.NO.=	49	X=	.78000000E+00	F(X)=	.18036717E+01
PT.NO.=	50	X=	.79000000E+00	F(X)=	.17917118E+01
PT.NO.=	51	X=	.80000000E+00	F(X)=	.17800000E+01
PT.NO.=	52	X=	.81000000E+00	F(X)=	.17685379E+01
PT.NO.=	53	X=	.82000000E+00	F(X)=	.17573175E+01
PT.NO.=	54	X=	.83000000E+00	F(X)=	.17463280E+01
PT.NO.=	55	X=	.84000000E+00	F(X)=	.17355591E+01
PT.NO.=	56	X=	.85000000E+00	F(X)=	.17250000E+01
PT.NO.=	57	X=	.86000000E+00	F(X)=	.17146404E+01
PT.NO.=	58	X=	.87000000E+00	F(X)=	.17044704E+01
PT.NO.=	59	X=	.88000000E+00	F(X)=	.16944801E+01
PT.NO.=	60	X=	.89000000E+00	F(X)=	.16846599E+01
PT.NO.=	61	X=	.90000000E+00	F(X)=	.16750000E+01
PT.NO.=	62	X=	.91000000E+00	F(X)=	.16654925E+01
PT.NO.=	63	X=	.92000000E+00	F(X)=	.16561371E+01
PT.NO.=	64	X=	.93000000E+00	F(X)=	.16469354E+01
PT.NO.=	65	X=	.94000000E+00	F(X)=	.16378892E+01
PT.NO.=	66	X=	.95000000E+00	F(X)=	.16290000E+01
PT.NO.=	67	X=	.96000000E+00	F(X)=	.16202697E+01
PT.NO.=	68	X=	.97000000E+00	F(X)=	.16117014E+01
PT.NO.=	69	X=	.98000000E+00	F(X)=	.16032982E+01
PT.NO.=	70	X=	.99000000E+00	F(X)=	.15950633E+01
PT.NO.=	71	X=	.10000000E+01	F(X)=	.15870000E+01
PT.NO.=	72	X=	.10100000E+01	F(X)=	.15791086E+01
PT.NO.=	73	X=	.10200000E+01	F(X)=	.15713774E+01
PT.NO.=	74	X=	.10300000E+01	F(X)=	.15637919E+01
PT.NO.=	75	X=	.10400000E+01	F(X)=	.15563376E+01
PT.NO.=	76	X=	.10500000E+01	F(X)=	.15490000E+01
PT.NO.=	77	X=	.10600000E+01	F(X)=	.15417680E+01
PT.NO.=	78	X=	.10700000E+01	F(X)=	.15346451E+01
PT.NO.=	79	X=	.10800000E+01	F(X)=	.15276382E+01
PT.NO.=	80	X=	.10900000E+01	F(X)=	.15207641E+01
PT.NO.=	81	X=	.11000000E+01	F(X)=	.15140000E+01

TABLE 2. (CONTINUED)

PT.NO.=	82	X=	.11100000E+01	F(X)=	.15073793E+01
PT.NO.=	83	X=	.11200000E+01	F(X)=	.15008822E+01
PT.NO.=	84	X=	.11300000E+01	F(X)=	.14966955E+01
PT.NO.=	85	X=	.11400000E+01	F(X)=	.14882058E+01
PT.NO.=	86	X=	.11500000E+01	F(X)=	.14820000E+01
PT.NO.=	87	X=	.11600000E+01	F(X)=	.14758667E+01
PT.NO.=	88	X=	.11700000E+01	F(X)=	.14698020E+01
PT.NO.=	89	X=	.11800000E+01	F(X)=	.14638040E+01
PT.NO.=	90	X=	.11900000E+01	F(X)=	.14578706E+01
PT.NO.=	91	X=	.12000000E+01	F(X)=	.14520000E+01
PT.NO.=	92	X=	.12100000E+01	F(X)=	.14461940E+01
PT.NO.=	93	X=	.12200000E+01	F(X)=	.14404698E+01
PT.NO.=	94	X=	.12300000E+01	F(X)=	.14348687E+01
PT.NO.=	95	X=	.12400000E+01	F(X)=	.14293617E+01
PT.NO.=	96	X=	.12500000E+01	F(X)=	.14240000E+01
PT.NO.=	97	X=	.12600000E+01	F(X)=	.14188054E+01
PT.NO.=	98	X=	.12700000E+01	F(X)=	.14137427E+01
PT.NO.=	99	X=	.12800000E+01	F(X)=	.14087773E+01
PT.NO.=	100	X=	.12900000E+01	F(X)=	.14038746E+01
PT.NO.=	101	X=	.13000000E+01	F(X)=	.13990000E+01
PT.NO.=	102	X=	.13100000E+01	F(X)=	.13941282E+01
PT.NO.=	103	X=	.13200000E+01	F(X)=	.13892712E+01
PT.NO.=	104	X=	.13300000E+01	F(X)=	.13844500E+01
PT.NO.=	105	X=	.13400000E+01	F(X)=	.13796869E+01
PT.NO.=	106	X=	.13500000E+01	F(X)=	.13750000E+01
PT.NO.=	107	X=	.13600000E+01	F(X)=	.13704096E+01
PT.NO.=	108	X=	.13700000E+01	F(X)=	.13659165E+01
PT.NO.=	109	X=	.13800000E+01	F(X)=	.13615186E+01
PT.NO.=	110	X=	.13900000E+01	F(X)=	.13572138E+01
PT.NO.=	111	X=	.14000000E+01	F(X)=	.13530000E+01
PT.NO.=	112	X=	.14100000E+01	F(X)=	.13488734E+01
PT.NO.=	113	X=	.14200000E+01	F(X)=	.13448229E+01
PT.NO.=	114	X=	.14300000E+01	F(X)=	.13408357E+01
PT.NO.=	115	X=	.14400000E+01	F(X)=	.13368990E+01
PT.NO.=	116	X=	.14500000E+01	F(X)=	.13330000E+01
PT.NO.=	117	X=	.14600000E+01	F(X)=	.13291289E+01
PT.NO.=	118	X=	.14700000E+01	F(X)=	.13252861E+01
PT.NO.=	119	X=	.14800000E+01	F(X)=	.13214828E+01
PT.NO.=	120	X=	.14900000E+01	F(X)=	.13177163E+01
PT.NO.=	121	X=	.15000000E+01	F(X)=	.13140000E+01
PT.NO.=	122	X=	.15100000E+01	F(X)=	.13103309E+01
PT.NO.=	123	X=	.15200000E+01	F(X)=	.13067048E+01
PT.NO.=	124	X=	.15300000E+01	F(X)=	.13031132E+01
PT.NO.=	125	X=	.15400000E+01	F(X)=	.12995674E+01
PT.NO.=	126	X=	.15500000E+01	F(X)=	.12960000E+01
PT.NO.=	127	X=	.15600000E+01	F(X)=	.12926476E+01
PT.NO.=	128	X=	.15700000E+01	F(X)=	.12889729E+01
PT.NO.=	129	X=	.15800000E+01	F(X)=	.12855443E+01
PT.NO.=	130	X=	.15900000E+01	F(X)=	.12822106E+01
PT.NO.=	131	X=	.16000000E+01	F(X)=	.12790000E+01
PT.NO.=	132	X=	.16100000E+01	F(X)=	.12759268E+01
PT.NO.=	133	X=	.16200000E+01	F(X)=	.12729478E+01
PT.NO.=	134	X=	.16300000E+01	F(X)=	.12700054E+01
PT.NO.=	135	X=	.16400000E+01	F(X)=	.12670420E+01
PT.NO.=	136	X=	.16500000E+01	F(X)=	.12640000E+01
PT.NO.=	137	X=	.16600000E+01	F(X)=	.12608411E+01
PT.NO.=	138	X=	.16700000E+01	F(X)=	.12576039E+01
PT.NO.=	139	X=	.16800000E+01	F(X)=	.12543661E+01
PT.NO.=	140	X=	.16900000E+01	F(X)=	.12511255E+01
PT.NO.=	141	X=	.17000000E+01	F(X)=	.12480000E+01
PT.NO.=	142	X=	.17100000E+01	F(X)=	.12450128E+01
PT.NO.=	143	X=	.17200000E+01	F(X)=	.12421487E+01
PT.NO.=	144	X=	.17300000E+01	F(X)=	.12393783E+01
PT.NO.=	145	X=	.17400000E+01	F(X)=	.12366720E+01
PT.NO.=	146	X=	.17500000E+01	F(X)=	.12340000E+01
PT.NO.=	147	X=	.17600000E+01	F(X)=	.12313399E+01
PT.NO.=	148	X=	.17700000E+01	F(X)=	.12286972E+01
PT.NO.=	149	X=	.17800000E+01	F(X)=	.12260646E+01
PT.NO.=	150	X=	.17900000E+01	F(X)=	.12235146E+01
PT.NO.=	151	X=	.18000000E+01	F(X)=	.12210000E+01
PT.NO.=	152	X=	.18100000E+01	F(X)=	.12185477E+01
PT.NO.=	153	X=	.18200000E+01	F(X)=	.12161425E+01
PT.NO.=	154	X=	.18300000E+01	F(X)=	.12137634E+01
PT.NO.=	155	X=	.18400000E+01	F(X)=	.12113695E+01
PT.NO.=	156	X=	.18500000E+01	F(X)=	.12090000E+01
PT.NO.=	157	X=	.18600000E+01	F(X)=	.12065812E+01
PT.NO.=	158	X=	.18700000E+01	F(X)=	.12041488E+01
PT.NO.=	159	X=	.18800000E+01	F(X)=	.12017258E+01
PT.NO.=	160	X=	.18900000E+01	F(X)=	.11993352E+01
PT.NO.=	161	X=	.19000000E+01	F(X)=	.11970000E+01
PT.NO.=	162	X=	.19100000E+01	F(X)=	.11947355E+01

TABLE 2. (CONTINUED)

PT.NO.=	163	X=	.19200000E+01	F(X)=	.11925264E+01
PT.NO.=	164	X=	.19300000E+01	F(X)=	.11903494E+01
PT.NO.=	165	X=	.19400000E+01	F(X)=	.11881817E+01
PT.NO.=	166	X=	.19500000E+01	F(X)=	.11860000E+01
PT.NO.=	167	X=	.19600000E+01	F(X)=	.11837887E+01
PT.NO.=	168	X=	.19700000E+01	F(X)=	.11815618E+01
PT.NO.=	169	X=	.19800000E+01	F(X)=	.11793405E+01
PT.NO.=	170	X=	.19900000E+01	F(X)=	.11771461E+01
PT.NO.=	171	X=	.20000000E+01	F(X)=	.11750000E+01
PT.NO.=	172	X=	.20100000E+01	F(X)=	.11729185E+01
PT.NO.=	173	X=	.20200000E+01	F(X)=	.11708987E+01
PT.NO.=	174	X=	.20300000E+01	F(X)=	.11689324E+01
PT.NO.=	175	X=	.20400000E+01	F(X)=	.11670118E+01
PT.NO.=	176	X=	.20500000E+01	F(X)=	.11651288E+01
PT.NO.=	177	X=	.20600000E+01	F(X)=	.11632755E+01
PT.NO.=	178	X=	.20700000E+01	F(X)=	.11614440E+01
PT.NO.=	179	X=	.20800000E+01	F(X)=	.11596262E+01
PT.NO.=	180	X=	.20900000E+01	F(X)=	.11578142E+01
PT.NO.=	181	X=	.21000000E+01	F(X)=	.11560000E+01
PT.NO.=	182	X=	.21100000E+01	F(X)=	.11541777E+01
PT.NO.=	183	X=	.21200000E+01	F(X)=	.11523493E+01
PT.NO.=	184	X=	.21300000E+01	F(X)=	.11505190E+01
PT.NO.=	185	X=	.21400000E+01	F(X)=	.11486909E+01
PT.NO.=	186	X=	.21500000E+01	F(X)=	.11468692E+01
PT.NO.=	187	X=	.21600000E+01	F(X)=	.11450579E+01
PT.NO.=	188	X=	.21700000E+01	F(X)=	.11432613E+01
PT.NO.=	189	X=	.21800000E+01	F(X)=	.11414833E+01
PT.NO.=	190	X=	.21900000E+01	F(X)=	.11397282E+01
PT.NO.=	191	X=	.22000000E+01	F(X)=	.11380000E+01
PT.NO.=	192	X=	.22100000E+01	F(X)=	.11363018E+01
PT.NO.=	193	X=	.22200000E+01	F(X)=	.11346322E+01
PT.NO.=	194	X=	.22300000E+01	F(X)=	.11329886E+01
PT.NO.=	195	X=	.22400000E+01	F(X)=	.11313685E+01
PT.NO.=	196	X=	.22500000E+01	F(X)=	.11297694E+01
PT.NO.=	197	X=	.22600000E+01	F(X)=	.11281887E+01
PT.NO.=	198	X=	.22700000E+01	F(X)=	.11266240E+01
PT.NO.=	199	X=	.22800000E+01	F(X)=	.11250726E+01
PT.NO.=	200	X=	.22900000E+01	F(X)=	.11235321E+01
PT.NO.=	201	X=	.23000000E+01	F(X)=	.11220000E+01
PT.NO.=	202	X=	.23100000E+01	F(X)=	.11204741E+01
PT.NO.=	203	X=	.23200000E+01	F(X)=	.11189540E+01
PT.NO.=	204	X=	.23300000E+01	F(X)=	.11174397E+01
PT.NO.=	205	X=	.23400000E+01	F(X)=	.11159311E+01
PT.NO.=	206	X=	.23500000E+01	F(X)=	.11144283E+01
PT.NO.=	207	X=	.23600000E+01	F(X)=	.11129313E+01
PT.NO.=	208	X=	.23700000E+01	F(X)=	.11114399E+01
PT.NO.=	209	X=	.23800000E+01	F(X)=	.11099543E+01
PT.NO.=	210	X=	.23900000E+01	F(X)=	.11084743E+01
PT.NO.=	211	X=	.24000000E+01	F(X)=	.11070000E+01
PT.NO.=	212	X=	.24100000E+01	F(X)=	.11055318E+01
PT.NO.=	213	X=	.24200000E+01	F(X)=	.11040718E+01
PT.NO.=	214	X=	.24300000E+01	F(X)=	.11026227E+01
PT.NO.=	215	X=	.24400000E+01	F(X)=	.11011870E+01
PT.NO.=	216	X=	.24500000E+01	F(X)=	.10997673E+01
PT.NO.=	217	X=	.24600000E+01	F(X)=	.10983663E+01
PT.NO.=	218	X=	.24700000E+01	F(X)=	.10969864E+01
PT.NO.=	219	X=	.24800000E+01	F(X)=	.10956304E+01
PT.NO.=	220	X=	.24900000E+01	F(X)=	.10943007E+01
PT.NO.=	221	X=	.25000000E+01	F(X)=	.10930000E+01
PT.NO.=	222	X=	.25100000E+01	F(X)=	.10917297E+01
PT.NO.=	223	X=	.25200000E+01	F(X)=	.10904867E+01
PT.NO.=	224	X=	.25300000E+01	F(X)=	.10892665E+01
PT.NO.=	225	X=	.25400000E+01	F(X)=	.10880648E+01
PT.NO.=	226	X=	.25500000E+01	F(X)=	.10868773E+01
PT.NO.=	227	X=	.25600000E+01	F(X)=	.10856996E+01
PT.NO.=	228	X=	.25700000E+01	F(X)=	.10845274E+01
PT.NO.=	229	X=	.25800000E+01	F(X)=	.10833563E+01
PT.NO.=	230	X=	.25900000E+01	F(X)=	.10821820E+01
PT.NO.=	231	X=	.26000000E+01	F(X)=	.10810000E+01
PT.NO.=	232	X=	.26100000E+01	F(X)=	.10798073E+01
PT.NO.=	233	X=	.26200000E+01	F(X)=	.10786055E+01
PT.NO.=	234	X=	.26300000E+01	F(X)=	.10773973E+01
PT.NO.=	235	X=	.26400000E+01	F(X)=	.10761857E+01
PT.NO.=	236	X=	.26500000E+01	F(X)=	.10749733E+01
PT.NO.=	237	X=	.26600000E+01	F(X)=	.10737631E+01
PT.NO.=	238	X=	.26700000E+01	F(X)=	.10725579E+01
PT.NO.=	239	X=	.26800000E+01	F(X)=	.10713604E+01
PT.NO.=	240	X=	.26900000E+01	F(X)=	.10701735E+01
PT.NO.=	241	X=	.27000000E+01	F(X)=	.10690000E+01
PT.NO.=	242	X=	.27100000E+01	F(X)=	.10678421E+01
PT.NO.=	243	X=	.27200000E+01	F(X)=	.10666995E+01
PT.NO.=	244	X=	.27300000E+01	F(X)=	.10655713E+01
PT.NO.=	245	X=	.27400000E+01	F(X)=	.10644565E+01
PT.NO.=	246	X=	.27500000E+01	F(X)=	.10633543E+01

TABLE 2. (CONTINUED)

PT.NO.=	247	X=	.27600000E+01	F(X)=	.10622638E+01
PT.NO.=	248	X=	.27700000E+01	F(X)=	.10611840E+01
PT.NO.=	249	X=	.27800000E+01	F(X)=	.10601141E+01
PT.NO.=	250	X=	.27900000E+01	F(X)=	.10590530E+01
PT.NO.=	251	X=	.28000000E+01	F(X)=	.10580000E+01
PT.NO.=	252	X=	.28100000E+01	F(X)=	.10569543E+01
PT.NO.=	253	X=	.28200000E+01	F(X)=	.10559166E+01
PT.NO.=	254	X=	.28300000E+01	F(X)=	.10548877E+01
PT.NO.=	255	X=	.28400000E+01	F(X)=	.10538683E+01
PT.NO.=	256	X=	.28500000E+01	F(X)=	.10528593E+01
PT.NO.=	257	X=	.28600000E+01	F(X)=	.10518616E+01
PT.NO.=	258	X=	.28700000E+01	F(X)=	.10508760E+01
PT.NO.=	259	X=	.28800000E+01	F(X)=	.10499033E+01
PT.NO.=	260	X=	.28900000E+01	F(X)=	.10489444E+01
PT.NO.=	261	X=	.29000000E+01	F(X)=	.10480000E+01
PT.NO.=	262	X=	.29100000E+01	F(X)=	.10470705E+01
PT.NO.=	263	X=	.29200000E+01	F(X)=	.10461540E+01
PT.NO.=	264	X=	.29300000E+01	F(X)=	.10452481E+01
PT.NO.=	265	X=	.29400000E+01	F(X)=	.10443504E+01
PT.NO.=	266	X=	.29500000E+01	F(X)=	.10434584E+01
PT.NO.=	267	X=	.29600000E+01	F(X)=	.10425697E+01
PT.NO.=	268	X=	.29700000E+01	F(X)=	.10416820E+01
PT.NO.=	269	X=	.29800000E+01	F(X)=	.10407927E+01
PT.NO.=	270	X=	.29900000E+01	F(X)=	.10398995E+01
PT.NO.=	271	X=	.30000000E+01	F(X)=	.10390000E+01
PT.NO.=	272	X=	.30100000E+01	F(X)=	.10380926E+01
PT.NO.=	273	X=	.30200000E+01	F(X)=	.10371792E+01
PT.NO.=	274	X=	.30300000E+01	F(X)=	.10362628E+01
PT.NO.=	275	X=	.30400000E+01	F(X)=	.10353461E+01
PT.NO.=	276	X=	.30500000E+01	F(X)=	.10344321E+01
PT.NO.=	277	X=	.30600000E+01	F(X)=	.10335234E+01
PT.NO.=	278	X=	.30700000E+01	F(X)=	.10326231E+01
PT.NO.=	279	X=	.30800000E+01	F(X)=	.10317338E+01
PT.NO.=	280	X=	.30900000E+01	F(X)=	.10308585E+01
PT.NO.=	281	X=	.31000000E+01	F(X)=	.10300000E+01
PT.NO.=	282	X=	.31100000E+01	F(X)=	.10291602E+01
PT.NO.=	283	X=	.31200000E+01	F(X)=	.10283370E+01
PT.NO.=	284	X=	.31300000E+01	F(X)=	.10275276E+01
PT.NO.=	285	X=	.31400000E+01	F(X)=	.10267291E+01
PT.NO.=	286	X=	.31500000E+01	F(X)=	.10259384E+01
PT.NO.=	287	X=	.31600000E+01	F(X)=	.10251526E+01
PT.NO.=	288	X=	.31700000E+01	F(X)=	.10243688E+01
PT.NO.=	289	X=	.31800000E+01	F(X)=	.10235841E+01
PT.NO.=	290	X=	.31900000E+01	F(X)=	.10227955E+01
PT.NO.=	291	X=	.32000000E+01	F(X)=	.10220000E+01
PT.NO.=	292	X=	.32100000E+01	F(X)=	.10211958E+01
PT.NO.=	293	X=	.32200000E+01	F(X)=	.10203847E+01
PT.NO.=	294	X=	.32300000E+01	F(X)=	.10195696E+01
PT.NO.=	295	X=	.32400000E+01	F(X)=	.10187536E+01
PT.NO.=	296	X=	.32500000E+01	F(X)=	.10179395E+01
PT.NO.=	297	X=	.32600000E+01	F(X)=	.10171302E+01
PT.NO.=	298	X=	.32700000E+01	F(X)=	.10163287E+01
PT.NO.=	299	X=	.32800000E+01	F(X)=	.10155379E+01
PT.NO.=	300	X=	.32900000E+01	F(X)=	.10147607E+01
PT.NO.=	301	X=	.33000000E+01	F(X)=	.10140000E+01
PT.NO.=	302	X=	.33100000E+01	F(X)=	.10132578E+01
PT.NO.=	303	X=	.33200000E+01	F(X)=	.10125323E+01
PT.NO.=	304	X=	.33300000E+01	F(X)=	.10118208E+01
PT.NO.=	305	X=	.33400000E+01	F(X)=	.10111205E+01
PT.NO.=	306	X=	.33500000E+01	F(X)=	.10104286E+01
PT.NO.=	307	X=	.33600000E+01	F(X)=	.10097425E+01
PT.NO.=	308	X=	.33700000E+01	F(X)=	.10090593E+01
PT.NO.=	309	X=	.33800000E+01	F(X)=	.10083763E+01
PT.NO.=	310	X=	.33900000E+01	F(X)=	.10076908E+01
PT.NO.=	311	X=	.34000000E+01	F(X)=	.10070000E+01
PT.NO.=	312	X=	.34100000E+01	F(X)=	.10063019E+01
PT.NO.=	313	X=	.34200000E+01	F(X)=	.10055972E+01
PT.NO.=	314	X=	.34300000E+01	F(X)=	.10048874E+01
PT.NO.=	315	X=	.34400000E+01	F(X)=	.10041740E+01
PT.NO.=	316	X=	.34500000E+01	F(X)=	.10034584E+01
PT.NO.=	317	X=	.34600000E+01	F(X)=	.10027422E+01
PT.NO.=	318	X=	.34700000E+01	F(X)=	.10020268E+01
PT.NO.=	319	X=	.34800000E+01	F(X)=	.10013136E+01
PT.NO.=	320	X=	.34900000E+01	F(X)=	.10006042E+01
PT.NO.=	321	X=	.35000000E+01	F(X)=	.99990000E+00
PT.NO.=	322	X=	.35100000E+01	F(X)=	.99920221E+00
PT.NO.=	323	X=	.35200000E+01	F(X)=	.99851096E+00
PT.NO.=	324	X=	.35300000E+01	F(X)=	.99782612E+00
PT.NO.=	325	X=	.35400000E+01	F(X)=	.99714754E+00
PT.NO.=	326	X=	.35500000E+01	F(X)=	.99647510E+00
PT.NO.=	327	X=	.35600000E+01	F(X)=	.99580865E+00
PT.NO.=	328	X=	.35700000E+01	F(X)=	.99514805E+00
PT.NO.=	329	X=	.35800000E+01	F(X)=	.99449317E+00
PT.NO.=	330	X=	.35900000E+01	F(X)=	.99384387E+00
PT.NO.=	331	X=	.36000000E+01	F(X)=	.99320000E+00

TABLE 2. (CONTINUED)

PT.NO.=	332	X=	.36100000E+01	F(X)=	.99256140E+00
PT.NO.=	333	X=	.36200000E+01	F(X)=	.99192779E+00
PT.NO.=	334	X=	.36300000E+01	F(X)=	.99129884E+00
PT.NO.=	335	X=	.36400000E+01	F(X)=	.99067424E+00
PT.NO.=	336	X=	.36500000E+01	F(X)=	.99005366E+00
PT.NO.=	337	X=	.36600000E+01	F(X)=	.98943678E+00
PT.NO.=	338	X=	.36700000E+01	F(X)=	.98882330E+00
PT.NO.=	339	X=	.36800000E+01	F(X)=	.98821289E+00
PT.NO.=	340	X=	.36900000E+01	F(X)=	.98760523E+00
PT.NO.=	341	X=	.37000000E+01	F(X)=	.98700000E+00
PT.NO.=	342	X=	.37100000E+01	F(X)=	.98639698E+00
PT.NO.=	343	X=	.37200000E+01	F(X)=	.98579629E+00
PT.NO.=	344	X=	.37300000E+01	F(X)=	.98519812E+00
PT.NO.=	345	X=	.37400000E+01	F(X)=	.98460271E+00
PT.NO.=	346	X=	.37500000E+01	F(X)=	.98401027E+00
PT.NO.=	347	X=	.37600000E+01	F(X)=	.98342101E+00
PT.NO.=	348	X=	.37700000E+01	F(X)=	.98283514E+00
PT.NO.=	349	X=	.37800000E+01	F(X)=	.98225287E+00
PT.NO.=	350	X=	.37900000E+01	F(X)=	.98167442E+00
PT.NO.=	351	X=	.38000000E+01	F(X)=	.98110000E+00
PT.NO.=	352	X=	.38100000E+01	F(X)=	.98052970E+00
PT.NO.=	353	X=	.38200000E+01	F(X)=	.97996310E+00
PT.NO.=	354	X=	.38300000E+01	F(X)=	.97939968E+00
PT.NO.=	355	X=	.38400000E+01	F(X)=	.97883891E+00
PT.NO.=	356	X=	.38500000E+01	F(X)=	.97828025E+00
PT.NO.=	357	X=	.38600000E+01	F(X)=	.97772317E+00
PT.NO.=	358	X=	.38700000E+01	F(X)=	.97716713E+00
PT.NO.=	359	X=	.38800000E+01	F(X)=	.97661162E+00
PT.NO.=	360	X=	.38900000E+01	F(X)=	.97605608E+00
PT.NO.=	361	X=	.39000000E+01	F(X)=	.97550000E+00
PT.NO.=	362	X=	.39100000E+01	F(X)=	.97494304E+00
PT.NO.=	363	X=	.39200000E+01	F(X)=	.97438572E+00
PT.NO.=	364	X=	.39300000E+01	F(X)=	.97382876E+00
PT.NO.=	365	X=	.39400000E+01	F(X)=	.97327286E+00
PT.NO.=	366	X=	.39500000E+01	F(X)=	.97271874E+00
PT.NO.=	367	X=	.39600000E+01	F(X)=	.97216713E+00
PT.NO.=	368	X=	.39700000E+01	F(X)=	.97161873E+00
PT.NO.=	369	X=	.39800000E+01	F(X)=	.97107426E+00
PT.NO.=	370	X=	.39900000E+01	F(X)=	.97053445E+00
PT.NO.=	371	X=	.40000000E+01	F(X)=	.97000000E+00
PT.NO.=	372	X=	.40100000E+01	F(X)=	.96947143E+00
PT.NO.=	373	X=	.40200000E+01	F(X)=	.96894840E+00
PT.NO.=	374	X=	.40300000E+01	F(X)=	.96843039E+00
PT.NO.=	375	X=	.40400000E+01	F(X)=	.96791687E+00
PT.NO.=	376	X=	.40500000E+01	F(X)=	.96740729E+00
PT.NO.=	377	X=	.40600000E+01	F(X)=	.96690113E+00
PT.NO.=	378	X=	.40700000E+01	F(X)=	.96639786E+00
PT.NO.=	379	X=	.40800000E+01	F(X)=	.96589693E+00
PT.NO.=	380	X=	.40900000E+01	F(X)=	.96539782E+00
PT.NO.=	381	X=	.41000000E+01	F(X)=	.96490000E+00
PT.NO.=	382	X=	.41100000E+01	F(X)=	.96440305E+00
PT.NO.=	383	X=	.41200000E+01	F(X)=	.96390707E+00
PT.NO.=	384	X=	.41300000E+01	F(X)=	.96341228E+00
PT.NO.=	385	X=	.41400000E+01	F(X)=	.96291888E+00
PT.NO.=	386	X=	.41500000E+01	F(X)=	.96242710E+00
PT.NO.=	387	X=	.41600000E+01	F(X)=	.96193715E+00
PT.NO.=	388	X=	.41700000E+01	F(X)=	.96144925E+00
PT.NO.=	389	X=	.41800000E+01	F(X)=	.96096361E+00
PT.NO.=	390	X=	.41900000E+01	F(X)=	.96048046E+00
PT.NO.=	391	X=	.42000000E+01	F(X)=	.96000000E+00
PT.NO.=	392	X=	.42100000E+01	F(X)=	.95952236E+00
PT.NO.=	393	X=	.42200000E+01	F(X)=	.95904731E+00
PT.NO.=	394	X=	.42300000E+01	F(X)=	.95857451E+00
PT.NO.=	395	X=	.42400000E+01	F(X)=	.95810362E+00
PT.NO.=	396	X=	.42500000E+01	F(X)=	.95763432E+00
PT.NO.=	397	X=	.42600000E+01	F(X)=	.95716627E+00
PT.NO.=	398	X=	.42700000E+01	F(X)=	.95669915E+00
PT.NO.=	399	X=	.42800000E+01	F(X)=	.95623262E+00
PT.NO.=	400	X=	.42900000E+01	F(X)=	.95576635E+00
PT.NO.=	401	X=	.43000000E+01	F(X)=	.95530000E+00
PT.NO.=	402	X=	.43100000E+01	F(X)=	.95483339E+00
PT.NO.=	403	X=	.43200000E+01	F(X)=	.95436689E+00
PT.NO.=	404	X=	.43300000E+01	F(X)=	.95390100E+00
PT.NO.=	405	X=	.43400000E+01	F(X)=	.95343624E+00
PT.NO.=	406	X=	.43500000E+01	F(X)=	.95297312E+00
PT.NO.=	407	X=	.43600000E+01	F(X)=	.95251215E+00
PT.NO.=	408	X=	.50000000E+01	F(X)=	.92690000E+00
PT.NO.=	409	X=	.60000000E+01	F(X)=	.89630000E+00
PT.NO.=	410	X=	.70000000E+01	F(X)=	.87270000E+00
PT.NO.=	411	X=	.80000000E+01	F(X)=	.85380000E+00
PT.NO.=	412	X=	.90000000E+01	F(X)=	.83790000E+00
PT.NO.=	413	X=	.10000000E+02	F(X)=	.82420000E+00
PT.NO.=	414	X=	.11000000E+02	F(X)=	.81196920E+00
PT.NO.=	415	X=	.12000000E+02	F(X)=	.80095600E+00

TABLE 2. (CONTINUED)

PT.NO.=	416	X=	.13000000E+02	F(X)=	.79104803E+00
PT.NO.=	417	X=	.14000000E+02	F(X)=	.78213294E+00
PT.NO.=	418	X=	.15000000E+02	F(X)=	.77404834E+00
PT.NO.=	419	X=	.16000000E+02	F(X)=	.76683187E+00
PT.NO.=	420	X=	.17000000E+02	F(X)=	.76022118E+00
PT.NO.=	421	X=	.18000000E+02	F(X)=	.75415388E+00
PT.NO.=	422	X=	.19000000E+02	F(X)=	.74851761E+00
PT.NO.=	423	X=	.20000000E+02	F(X)=	.74320000E+00
PT.NO.=	424	X=	.21000000E+02	F(X)=	.73810636E+00
PT.NO.=	425	X=	.22000000E+02	F(X)=	.73321267E+00
PT.NO.=	426	X=	.23000000E+02	F(X)=	.72851259E+00
PT.NO.=	427	X=	.24000000E+02	F(X)=	.72399977E+00
PT.NO.=	428	X=	.25000000E+02	F(X)=	.71966787E+00
PT.NO.=	429	X=	.26000000E+02	F(X)=	.71551053E+00
PT.NO.=	430	X=	.27000000E+02	F(X)=	.71152142E+00
PT.NO.=	431	X=	.28000000E+02	F(X)=	.70769420E+00
PT.NO.=	432	X=	.29000000E+02	F(X)=	.70402250E+00
PT.NO.=	433	X=	.30000000E+02	F(X)=	.70050000E+00
PT.NO.=	434	X=	.31000000E+02	F(X)=	.69712006E+00
PT.NO.=	435	X=	.32000000E+02	F(X)=	.69387491E+00
PT.NO.=	436	X=	.33000000E+02	F(X)=	.69075650E+00
PT.NO.=	437	X=	.34000000E+02	F(X)=	.68775678E+00
PT.NO.=	438	X=	.35000000E+02	F(X)=	.68486769E+00
PT.NO.=	439	X=	.36000000E+02	F(X)=	.68208119E+00
PT.NO.=	440	X=	.37000000E+02	F(X)=	.67938923E+00
PT.NO.=	441	X=	.38000000E+02	F(X)=	.67678374E+00
PT.NO.=	442	X=	.39000000E+02	F(X)=	.67425668E+00
PT.NO.=	443	X=	.40000000E+02	F(X)=	.67180000E+00
PT.NO.=	444	X=	.41000000E+02	F(X)=	.66940671E+00
PT.NO.=	445	X=	.42000000E+02	F(X)=	.66707410E+00
PT.NO.=	446	X=	.43000000E+02	F(X)=	.66480052E+00
PT.NO.=	447	X=	.44000000E+02	F(X)=	.66258432E+00
PT.NO.=	448	X=	.45000000E+02	F(X)=	.66042386E+00
PT.NO.=	449	X=	.46000000E+02	F(X)=	.65831749E+00
PT.NO.=	450	X=	.47000000E+02	F(X)=	.65626357E+00
PT.NO.=	451	X=	.48000000E+02	F(X)=	.65426044E+00
PT.NO.=	452	X=	.49000000E+02	F(X)=	.65230647E+00
PT.NO.=	453	X=	.50000000E+02	F(X)=	.65040000E+00
PT.NO.=	454	X=	.51000000E+02	F(X)=	.64853930E+00
PT.NO.=	455	X=	.52000000E+02	F(X)=	.64672230E+00
PT.NO.=	456	X=	.53000000E+02	F(X)=	.64494684E+00
PT.NO.=	457	X=	.54000000E+02	F(X)=	.64321075E+00
PT.NO.=	458	X=	.55000000E+02	F(X)=	.64151187E+00
PT.NO.=	459	X=	.56000000E+02	F(X)=	.63984804E+00
PT.NO.=	460	X=	.57000000E+02	F(X)=	.63821710E+00
PT.NO.=	461	X=	.58000000E+02	F(X)=	.63661689E+00
PT.NO.=	462	X=	.59000000E+02	F(X)=	.63504524E+00
PT.NO.=	463	X=	.60000000E+02	F(X)=	.63350000E+00
PT.NO.=	464	X=	.61000000E+02	F(X)=	.63197938E+00
PT.NO.=	465	X=	.62000000E+02	F(X)=	.63048309E+00
PT.NO.=	466	X=	.63000000E+02	F(X)=	.62901122E+00
PT.NO.=	467	X=	.64000000E+02	F(X)=	.62756388E+00
PT.NO.=	468	X=	.65000000E+02	F(X)=	.62614116E+00
PT.NO.=	469	X=	.66000000E+02	F(X)=	.62474314E+00
PT.NO.=	470	X=	.67000000E+02	F(X)=	.62336992E+00
PT.NO.=	471	X=	.68000000E+02	F(X)=	.62202160E+00
PT.NO.=	472	X=	.69000000E+02	F(X)=	.62069826E+00
PT.NO.=	473	X=	.70000000E+02	F(X)=	.61940000E+00
PT.NO.=	474	X=	.71000000E+02	F(X)=	.61812670E+00
PT.NO.=	475	X=	.72000000E+02	F(X)=	.61687735E+00
PT.NO.=	476	X=	.73000000E+02	F(X)=	.61565076E+00
PT.NO.=	477	X=	.74000000E+02	F(X)=	.61444571E+00
PT.NO.=	478	X=	.75000000E+02	F(X)=	.61326099E+00
PT.NO.=	479	X=	.76000000E+02	F(X)=	.61209539E+00
PT.NO.=	480	X=	.77000000E+02	F(X)=	.61094771E+00
PT.NO.=	481	X=	.78000000E+02	F(X)=	.60981672E+00
PT.NO.=	482	X=	.79000000E+02	F(X)=	.60870122E+00
PT.NO.=	483	X=	.80000000E+02	F(X)=	.60760000E+00
PT.NO.=	484	X=	.81000000E+02	F(X)=	.60651204E+00
PT.NO.=	485	X=	.82000000E+02	F(X)=	.60543710E+00
PT.NO.=	486	X=	.83000000E+02	F(X)=	.60437513E+00
PT.NO.=	487	X=	.84000000E+02	F(X)=	.60332607E+00
PT.NO.=	488	X=	.85000000E+02	F(X)=	.60228987E+00
PT.NO.=	489	X=	.86000000E+02	F(X)=	.60126648E+00
PT.NO.=	490	X=	.87000000E+02	F(X)=	.60025585E+00
PT.NO.=	491	X=	.88000000E+02	F(X)=	.59925793E+00
PT.NO.=	492	X=	.89000000E+02	F(X)=	.59827266E+00
PT.NO.=	493	X=	.90000000E+02	F(X)=	.59730000E+00
PT.NO.=	494	X=	.91000000E+02	F(X)=	.59633983E+00
PT.NO.=	495	X=	.92000000E+02	F(X)=	.59539183E+00
PT.NO.=	496	X=	.93000000E+02	F(X)=	.59445562E+00
PT.NO.=	497	X=	.94000000E+02	F(X)=	.59353081E+00

TABLE 2. (CONCLUDED)

PT.NO.=	498	X=	.95000000E+02	F(X)=	.59261703E+00
PT.NO.=	499	X=	.96000000E+02	F(X)=	.59171388E+00
PT.NO.=	500	X=	.97000000E+02	F(X)=	.59082098E+00
PT.NO.=	501	X=	.98000000E+02	F(X)=	.58993796E+00
PT.NO.=	502	X=	.99000000E+02	F(X)=	.58906443E+00
PT.NO.=	503	X=	.10000000E+03	F(X)=	.58820000E+00

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been calculated by Svehla [2] for O_2 and NO. However, a literature search did not reveal viscosities of O_3 and NO_2 at elevated temperatures.

A method for the calculation of the viscosity of gases is given by Bird, et al. [3]

$$\epsilon/k = 0.77T_c \tag{11}$$

$$\sigma = 2.44 \left(\frac{T_c}{P_c}\right)^{1/3} \tag{12}$$

or

$$\sigma = 0.841 \quad (\tilde{V}_c)^{1/3} \tag{13}$$

where these functions are utilized in the Lennard-Jones potential

$$\phi(r) = 4\epsilon \left[\left(\frac{\sigma}{r}\right)^{12} - \left(\frac{\sigma}{r}\right)^{6} \right] \tag{14}$$

For O_3

$T_c = 268^oK \quad P_c = 67$ ATM

$\tilde{V}_c = 89.4\ cm^3/gm$ mole $\quad$ MW = 48.000

For NO_2

$T_c = 431.0\ ^oK \quad P_c = 100$ ATM

MW = 46.008

Utilizing (11) and (13) for O_3 and (11) and (12) for NO_2 produced the following potential functions for O_3 and NO_2:

GAS	ϵ/k	σ	MW
NO_2	331.8	3.97	46.008
O_3	206.4	3.76	48.000

The viscosity for each of these gases is then calculated using:

$$\mu = 2.6693 \times 10^{-5} \frac{\{(MW)\ T\}^{1/2}}{\sigma^2 \Omega_\mu} \tag{15}$$

Utilizing the potential functions given in *Table 2*, Equation (15), and the program developed in the previous section to calculate Ω_μ gives the viscosities of O_3 and NO_2.

A program was written to accomplish this called MUCALC and a listing of this program is given in Appendix B.

Table 3 gives the results of these calculations for NO_2 as a function of temperature while similar results for O_3 are given in *Table 4*. Finally results for the other gases of interest that have been taken from the literature are presented in *Table 5*. These gases are N_2, NO, and O_2. These results are given over the narrower range of temperature of interest for these reactions.

IV. COMPARISON OF RESULTS OF THIS METHOD WITH OTHER METHODS FOR CALCULATING MOLECULAR VISCOSITIES.

In order to determine the accuracy of the technique utilized to calculate molecular viscosities that were presented in the last section, a calculation was made for CO_2, results for which can be found in the literature. Hence, the properties for CO_2 were introduced into the program presented in the preceding section and the molecular viscosity for CO_2 was calculated. The program listing for this is presented in Appendix C. Note that this program is

TABLE 3. MOLECULAR VISCOSITY OF NO_2 AS A FUNCTION OF TEMPERATURE

T=	200.0	DEG K	XMU=	.788571E-04	POISES
T=	300.0	DEG K	XMU=	.119072E-03	POISES
T=	400.0	DEG K	XMU=	.158585E-03	POISES
T=	500.0	DEG K	XMU=	.195869E-03	POISES
T=	600.0	DEG K	XMU=	.230845E-03	POISES
T=	700.0	DEG K	XMU=	.263323E-03	POISES
T=	800.0	DEG K	XMU=	.293947E-03	POISES
T=	900.0	DEG K	XMU=	.322822E-03	POISES
T=	1000.0	DEG K	XMU=	.350062E-03	POISES
T=	1100.0	DEG K	XMU=	.376161E-03	POISES
T=	1200.0	DEG K	XMU=	.401098E-03	POISES
T=	1300.0	DEG K	XMU=	.425035E-03	POISES
T=	1400.0	DEG K	XMU=	.448172E-03	POISES
T=	1500.0	DEG K	XMU=	.470553E-03	POISES
T=	1600.0	DEG K	XMU=	.492271E-03	POISES
T=	1700.0	DEG K	XMU=	.513371E-03	POISES
T=	1800.0	DEG K	XMU=	.533922E-03	POISES
T=	1900.0	DEG K	XMU=	.554007E-03	POISES
T=	2000.0	DEG K	XMU=	.573655E-03	POISES
T=	2100.0	DEG K	XMU=	.592902E-03	POISES
T=	2200.0	DEG K	XMU=	.611763E-03	POISES
T=	2300.0	DEG K	XMU=	.630257E-03	POISES
T=	2400.0	DEG K	XMU=	.648407E-03	POISES
T=	2500.0	DEG K	XMU=	.666236E-03	POISES
T=	2600.0	DEG K	XMU=	.683773E-03	POISES
T=	2700.0	DEG K	XMU=	.701051E-03	POISES
T=	2800.0	DEG K	XMU=	.718091E-03	POISES
T=	2900.0	DEG K	XMU=	.734898E-03	POISES
T=	3000.0	DEG K	XMU=	.751479E-03	POISES
T=	3100.0	DEG K	XMU=	.767844E-03	POISES
T=	3200.0	DEG K	XMU=	.784009E-03	POISES
T=	3300.0	DEG K	XMU=	.799997E-03	POISES
T=	3400.0	DEG K	XMU=	.815528E-03	POISES
T=	3500.0	DEG K	XMU=	.831510E-03	POISES
T=	3600.0	DEG K	XMU=	.847046E-03	POISES
T=	3700.0	DEG K	XMU=	.862436E-03	POISES
T=	3800.0	DEG K	XMU=	.877683E-03	POISES
T=	3900.0	DEG K	XMU=	.892788E-03	POISES
T=	4000.0	DEG K	XMU=	.907753E-03	POISES
T=	4100.0	DEG K	XMU=	.922579E-03	POISES
T=	4200.0	DEG K	XMU=	.937268E-03	POISES
T=	4300.0	DEG K	XMU=	.951822E-03	POISES
T=	4400.0	DEG K	XMU=	.966242E-03	POISES
T=	4500.0	DEG K	XMU=	.980531E-03	POISES
T=	4600.0	DEG K	XMU=	.994690E-03	POISES
T=	4700.0	DEG K	XMU=	.100872E-02	POISES
T=	4800.0	DEG K	XMU=	.102263E-02	POISES
T=	4900.0	DEG K	XMU=	.103641E-02	POISES
T=	5000.0	DEG K	XMU=	.105007E-02	POISES

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TABLE 4. MOLECULAR VISCOSITY OF O_3 AS A FUNCTION OF TEMPERATURE

T=	200.0	DEG K	XMU=	.114721E-03	POISES
T=	300.0	DEG K	XMU=	.170143E-03	POISES
T=	400.0	DEG K	XMU=	.220105E-03	POISES
T=	500.0	DEG K	XMU=	.265016E-03	POISES
T=	600.0	DEG K	XMU=	.305933E-03	POISES
T=	700.0	DEG K	XMU=	.343465E-03	POISES
T=	800.0	DEG K	XMU=	.378762E-03	POISES
T=	900.0	DEG K	XMU=	.412005E-03	POISES
T=	1000.0	DEG K	XMU=	.443569E-03	POISES
T=	1100.0	DEG K	XMU=	.473715E-03	POISES
T=	1200.0	DEG K	XMU=	.502723E-03	POISES
T=	1300.0	DEG K	XMU=	.530744E-03	POISES
T=	1400.0	DEG K	XMU=	.557867E-03	POISES
T=	1500.0	DEG K	XMU=	.584165E-03	POISES
T=	1600.0	DEG K	XMU=	.609728E-03	POISES
T=	1700.0	DEG K	XMU=	.634666E-03	POISES
T=	1800.0	DEG K	XMU=	.659055E-03	POISES
T=	1900.0	DEG K	XMU=	.682918E-03	POISES
T=	2000.0	DEG K	XMU=	.706301E-03	POISES
T=	2100.0	DEG K	XMU=	.729279E-03	POISES
T=	2200.0	DEG K	XMU=	.751907E-03	POISES
T=	2300.0	DEG K	XMU=	.774196E-03	POISES
T=	2400.0	DEG K	XMU=	.796152E-03	POISES
T=	2500.0	DEG K	XMU=	.817781E-03	POISES
T=	2600.0	DEG K	XMU=	.839084E-03	POISES
T=	2700.0	DEG K	XMU=	.860081E-03	POISES
T=	2800.0	DEG K	XMU=	.880766E-03	POISES
T=	2900.0	DEG K	XMU=	.901149E-03	POISES
T=	3000.0	DEG K	XMU=	.921239E-03	POISES
T=	3100.0	DEG K	XMU=	.941044E-03	POISES
T=	3200.0	DEG K	XMU=	.960573E-03	POISES
T=	3300.0	DEG K	XMU=	.979836E-03	POISES
T=	3400.0	DEG K	XMU=	.998845E-03	POISES
T=	3500.0	DEG K	XMU=	.101761E-02	POISES
T=	3600.0	DEG K	XMU=	.103615E-02	POISES
T=	3700.0	DEG K	XMU=	.105447E-02	POISES
T=	3800.0	DEG K	XMU=	.107260E-02	POISES
T=	3900.0	DEG K	XMU=	.109054E-02	POISES
T=	4000.0	DEG K	XMU=	.110831E-02	POISES
T=	4100.0	DEG K	XMU=	.112594E-02	POISES
T=	4200.0	DEG K	XMU=	.114344E-02	POISES
T=	4300.0	DEG K	XMU=	.116082E-02	POISES
T=	4400.0	DEG K	XMU=	.117809E-02	POISES
T=	4500.0	DEG K	XMU=	.119524E-02	POISES
T=	4600.0	DEG K	XMU=	.121228E-02	POISES
T=	4700.0	DEG K	XMU=	.122920E-02	POISES
T=	4800.0	DEG K	XMU=	.124602E-02	POISES
T=	4900.0	DEG K	XMU=	.126273E-02	POISES
T=	5000.0	DEG K	XMU=	.127933E-02	POISES

IXXXOEQ

TABLE 5. MOLECULAR VISCOSITIES FOR GASES INVOLVED IN THE $NO+O_3 \rightarrow NO_2 + O_2$ REACTION IN A N_2 CARRIER GAS.

TEMPERATURE °K	$\mu \times 10^6$-POISES N_2	$\mu \times 10^6$-POISES O_2	$\mu \times 10^6$-POISES NO	$\mu \times 10^6$-POISES NO_2	$\mu \times 10^6$-POISES O_3
200	131.3	147.9	136.5	78.9	114.7
300	177.7	206.4	192.0	119.1	170.1
400	217.2	256.5	239.7	158.6	220.1
500	252.7	301.0	282.0	195.9	265.0
600	285.4	341.4	320.5	230.8	305.9
700	315.6	379.1	356.2	263.3	343.5
800	344.0	414.8	389.9	293.9	378.8
900	371.0	448.5	421.9	322.8	412.0
1000	397.1	480.6	452.4	350.1	443.6

identical to the program presented in Appendix B except for the input conditions which are shown highlighted.

The comparison of the results from this method and that of Svehla are shown in *Table 6* for CO_2. The differences between the results range from 1.4 percent at 200 degrees K and increase monatonically to 3.3 percent at 5000 degrees K. Hence the conclusion is that the calculational method results in small deviations from accepted results for gases for which the more vigorous treatment has been exercised.

V. INTERPOLATION FOR $\mu_i = \mu_i(T)$

Having now established an interpolation routine for specie viscosities and having calculated specie viscosities for NO_2 and O_3 plus estimating the general magnitude of the error involved it was necessary to establish that the interpolation procedure was working correctly for individual species. This was accomplished by programming MUSPEC which is given in Appendix D. This program utilizes the viscosities of N_2, O_2, NO, NO_2, and O_3 as input and calculates the viscosities of these species at various temperatures between 500 degrees K and 600 degrees K.

The results of these calculations are shown in *Table 7*. These results can be compared with the data presented in *Table 5*. This comparison shows that the calculations are consistent and reasonable. Hence, the procedure for the calculation at the individual viscosities has been verified before proceeding to the mixture of these gases given in the next section.

VI. CALCULATION OF THE MOLECULAR VISCOSITY OF A MIXTURE OF GASES

Having established the calculational procedure for individual viscosities of gas species, the remaining task is to calculate same for the mixture resulting from the chemical reaction. The viscosity of the mixture of gases is not simply a mole fraction average of the individual viscosities but depends on the individual species in a more complex manner. The mathematical model due to Wilke is given [3] as follows

$$\mu_{mix} = \sum_{i=1}^{n} \frac{x_i \mu_i}{\sum_{j=1}^{n} x_j \Phi_{ij}} \tag{16}$$

TABLE 6. COMPARISON OF THE VISCOSITY CALCULATED BY THE PRESENT METHOD AND THAT OF SVEHLA.

MOLECULAR VISCOSITY OF CO_2 AS A FUNCTION OF TEMPERATURE

				*		**
T=	200.0	DEG K	XMU=	.101373E-03	POISES	.1028 E-03 POISES
T=	300.0	DEG K	XMU=	.149374E-03	POISES	.1520 E-03 POISES
T=	400.0	DEG K	XMU=	.192023E-03	POISES	.1960 E-03 POISES
T=	500.0	DEG K	XMU=	.230202E-03	POISES	.2354 E-03 POISES
T=	600.0	DEG K	XMU=	.264435E-03	POISES	.2714 E-03 POISES
T=	700.0	DEG K	XMU=	.296984E-03	POISES	.3048 E-03 POISES
T=	800.0	DEG K	XMU=	.326906E-03	POISES	.3359 E-03 POISES
T=	900.0	DEG K	XMU=	.355154E-03	POISES	.3653 E-03 POISES
T=	1000.0	DEG K	XMU=	.382021E-03	POISES	.3931 E-03 POISES
T=	1100.0	DEG K	XMU=	.407741E-03	POISES	.4197 E-03 POISES
T=	1200.0	DEG K	XMU=	.432507E-03	POISES	.4454 E-03 POISES
T=	1300.0	DEG K	XMU=	.456413E-03	POISES	.4702 E-03 POISES
T=	1400.0	DEG K	XMU=	.479537E-03	POISES	.4942 E-03 POISES
T=	1500.0	DEG K	XMU=	.501977E-03	POISES	.5176 E-03 POISES
T=	1600.0	DEG K	XMU=	.523845E-03	POISES	.5402 E-03 POISES
T=	1700.0	DEG K	XMU=	.545195E-03	POISES	.5623 E-03 POISES
T=	1800.0	DEG K	XMU=	.566058E-03	POISES	.5837 E-03 POISES
T=	1900.0	DEG K	XMU=	.586498E-03	POISES	.6046 E-03 POISES
T=	2000.0	DEG K	XMU=	.606588E-03	POISES	.6251 E-03 POISES
T=	2100.0	DEG K	XMU=	.626351E-03	POISES	.6450 E-03 POISES
T=	2200.0	DEG K	XMU=	.645794E-03	POISES	.6646 E-03 POISES
T=	2300.0	DEG K	XMU=	.664922E-03	POISES	.6838 E-03 POISES
T=	2400.0	DEG K	XMU=	.683741E-03	POISES	.7027 E-03 POISES
T=	2500.0	DEG K	XMU=	.702259E-03	POISES	.7213 E-03 POISES
T=	2600.0	DEG K	XMU=	.720482E-03	POISES	.7398 E-03 POISES
T=	2700.0	DEG K	XMU=	.738418E-03	POISES	.7580 E-03 POISES
T=	2800.0	DEG K	XMU=	.756075E-03	POISES	.7762 E-03 POISES
T=	2900.0	DEG K	XMU=	.773461E-03	POISES	.7942 E-03 POISES
T=	3000.0	DEG K	XMU=	.790588E-03	POISES	.8122 E-03 POISES
T=	3100.0	DEG K	XMU=	.807465E-03	POISES	.8302 E-03 POISES
T=	3200.0	DEG K	XMU=	.824107E-03	POISES	.8478 E-03 POISES
T=	3300.0	DEG K	XMU=	.840525E-03	POISES	.8651 E-03 POISES
T=	3400.0	DEG K	XMU=	.856736E-03	POISES	.8821 E-03 POISES
T=	3500.0	DEG K	XMU=	.872753E-03	POISES	.8990 E-03 POISES
T=	3600.0	DEG K	XMU=	.888596E-03	POISES	.9157 E-03 POISES
T=	3700.0	DEG K	XMU=	.904282E-03	POISES	.9322 E-03 POISES
T=	3800.0	DEG K	XMU=	.919831E-03	POISES	.9485 E-03 POISES
T=	3900.0	DEG K	XMU=	.935261E-03	POISES	.9647 E-03 POISES
T=	4000.0	DEG K	XMU=	.950578E-03	POISES	.9807 E-03 POISES
T=	4100.0	DEG K	XMU=	.965783E-03	POISES	.9966 E-03 POISES
T=	4200.0	DEG K	XMU=	.980479E-03	POISES	.1012 E-02 POISES
T=	4300.0	DEG K	XMU=	.995867E-03	POISES	.1023 E-02 POISES
T=	4400.0	DEG K	XMU=	.101075E-02	POISES	.1043 E-02 POISES
T=	4500.0	DEG K	XMU=	.102553E-02	POISES	.1059 E-02 POISES
T=	4600.0	DEG K	XMU=	.104020E-02	POISES	.1074 E-02 POISES
T=	4700.0	DEG K	XMU=	.105478E-02	POISES	.1089 E-02 POISES
T=	4800.0	DEG K	XMU=	.106926E-02	POISES	.1104 E-02 POISES
T=	4900.0	DEG K	XMU=	.108363E-02	POISES	.1119 E-02 POISES
T=	5000.0	DEG K	XMU=	.109791E-02	POISES	.1134 E-02 POISES

* PRESENT METHOD
** METHOD OF SVEHLA {2}

IXXX01V

TABLE 7. $\mu_I = \mu_I(T)$ FOR N_2, O_2, NO, NO_2, AND O_3

```
MU(1)= .25270000E+03  AT  T=    500.0DEG K
MU(2)= .30100000E+03  AT  T=    500.0DEG K
MU(3)= .24200000E+03  AT  T=    500.0DEG K
MU(4)= .19590000E+03  AT  T=    500.0DEG K
MU(5)= .26500000E+03  AT  T=    500.0DEG K

MU(1)= .25608922E+03  AT  T=    510.0DEG K
MU(2)= .30520190E+03  AT  T=    510.0DEG K
MU(3)= .28600164E+03  AT  T=    510.0DEG K
MU(4)= .19949842E+03  AT  T=    510.0DEG K
MU(5)= .25925554E+03  AT  T=    510.0DEG K

MU(1)= .25945206E+03  AT  T=    520.0DEG K
MU(2)= .30936338E+03  AT  T=    520.0DEG K
MU(3)= .28996722E+03  AT  T=    520.0DEG K
MU(4)= .20307346E+03  AT  T=    520.0DEG K
MU(5)= .27347355E+03  AT  T=    520.0DEG K

MU(1)= .26278847E+03  AT  T=    530.0DEG K
MU(2)= .31348609E+03  AT  T=    530.0DEG K
MU(3)= .29389762E+03  AT  T=    530.0DEG K
MU(4)= .20652894E+03  AT  T=    530.0DEG K
MU(5)= .27765432E+03  AT  T=    530.0DEG K

MU(1)= .26609841E+03  AT  T=    540.0DEG K
MU(2)= .31757172E+03  AT  T=    540.0DEG K
MU(3)= .29779374E+03  AT  T=    540.0DEG K
MU(4)= .21015231E+03  AT  T=    540.0DEG K
MU(5)= .28179810E+03  AT  T=    540.0DEG K

MU(1)= .26938185E+03  AT  T=    550.0DEG K
MU(2)= .32162192E+03  AT  T=    550.0DEG K
MU(3)= .30165645E+03  AT  T=    550.0DEG K
MU(4)= .21365559E+03  AT  T=    550.0DEG K
MU(5)= .24590520E+03  AT  T=    550.0DEG K

MU(1)= .27263873E+03  AT  T=    560.0DEG K
MU(2)= .32563837E+03  AT  T=    560.0DEG K
MU(3)= .30548665E+03  AT  T=    560.0DEG K
MU(4)= .21713442E+03  AT  T=    560.0DEG K
MU(5)= .28997588E+03  AT  T=    560.0DEG K

MU(1)= .27586903E+03  AT  T=    570.0DEG K
MU(2)= .32962273E+03  AT  T=    570.0DEG K
MU(3)= .30925522E+03  AT  T=    570.0DEG K
MU(4)= .22059855E+03  AT  T=    570.0DEG K
MU(5)= .29401042E+03  AT  T=    570.0DEG K

MU(1)= .27907271E+03  AT  T=    580.0DEG K
MU(2)= .33357666E+03  AT  T=    580.0DEG K
MU(3)= .31305304E+03  AT  T=    560.0DEG K
MU(4)= .22401769E+03  AT  T=    590.0DEG K
MU(5)= .29800910E+03  AT  T=    580.0DEG K

MU(1)= .28224471E+03  AT  T=    550.0DEG K
MU(2)= .33750188E+03  AT  T=    590.0DEG K
MU(3)= .31679101E+03  AT  T=    590.0DEG K
MU(4)= .22742150E+03  AT  T=    590.0DEG K
MU(5)= .30197220E+03  AT  T=    590.0DEG K
```

WJWDK4N

where

$$\Phi_{ij} = \frac{1}{\sqrt{8}} \left\{ 1 + \frac{MW_i}{MW_j} \right\}^{-\frac{1}{2}} \left\{ 1 + \left(\frac{\mu_i}{\mu_j} \right)^{\frac{1}{2}} \left(\frac{MW_j}{MW_i} \right)^{\frac{1}{4}} \right\}^2 \quad (17)$$

Equation (16) has been shown to reproduce measured values of μ_{mix} to within 2 percent for certain gases. The dependence of μ_{mix} on composition is extremely non-linear for certain gas mixtures, however.

Nevertheless, it is the best available technique and will be utilized here.

A test program was written to compute the viscosities of various mixtures of gases. The listing of this program is given in Appendix E. This program utilizes subroutine LAMVISC which performs the mixture calculations for the laminar viscosities according to the technique of Wilke given above. It also utilizes the subroutine MUSPEC which is a variation of Program MUSPEC discussed in an earlier section.

The results utilizing these methods are given in *Table 8* for various mixtures of N_2, O_2, NO, NO_2, and O_3. Comparing *Table 8* and *Table 5* will convince one that the results are reasonable.

VII. CONCLUSIONS

A computer code has been generated to determine laminar viscosities of gases as a function of temperature. This method is approximate but it provides results useful in making engineering analyses. The specific gases for which laminar viscosities were determined included NO_2 and O_3, but the method is applicable for other gases.

TABLE 8. $\mu_{mix} = \mu_{mix}$ (T) FOR VARIOUS MIXTURES OF N_2, O_2, NO, NO_2, and O_3 (MOLE FRACTIONS)

```
FOR THE FOLLOWING GAS MIXTURE -N2=  .700 O2= .300 NO= 0.000 NO2= 0.000 O3= 0.000
 MUMIX= .18631285E+03  AT T= .30000000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .700 O2= .050 NO=  .150 NO2=  .050 O3=  .050
 MUMIX= .18859141E+03  AT T= .30500000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .700 O2= .100 NO=  .100 NO2=  .050 O3=  .050
 MUMIX= .20832745E+03  AT T= .35000000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .600 O2= .100 NO=  .050 NO2=  .200 O3=  .050
 MUMIX= .22889949E+03  AT T= .40000000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .600 O2= .100 NO=  .100 NO2=  .100 O3=  .100
 MUMIX= .26701965E+03  AT T= .50000000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .600 O2= .050 NO=  .050 NO2=  .200 O3=  .100
 MUMIX= .27602886E+03  AT T= .52500000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .700 O2= .300 NO= 0.000 NO2= 0.000 O3= 0.000
 MUMIX= .18631285E+03  AT T= .30000000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .700 O2= .050 NO=  .150 NO2=  .050 O3=  .050
 MUMIX= .18859141E+03  AT T= .30500000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .700 O2= .100 NO=  .100 NO2=  .050 O3=  .050
 MUMIX= .20832745E+03  AT T= .25000000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .600 O2= .100 NO=  .050 NO2=  .200 O3=  .050
 MUMIX= .22889949E+03  AT T= .40000000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .600 O2= .100 NO=  .100 NO2=  .100 O3=  .100
 MUMIX= .26701965E+03  AT T= .50000000E+03

FOR THE FOLLOWING GAS MIXTURE -N2=  .600 O2= .050 NO=  .050 NO2=  .200 O3=  .100
 MUMIX= .27602886E+03  AT T= .52500000E+03
```

WJWDK45

APPENDIX A
PROGRAM LISTING FOR TEST - A ROUTINE TO CHECK THE ACCURACY OF THE CUBIC SPLINE INTERPOLATION ROUTINE

```
PROGRAM TEST        74/74    OPT=1              IXXX08L            FTN 4.6+433B       06/18/79

          PROGRAM TEST(OUTPUT,TAPE6=OUTPUT)
C   TEST PROGRAM FOR SPLINE FIT ROUTINE USING LAGRANGIAN POLYNOMIALS FOR END
C   POINT SLOPE CALCULATION
          DIMENSION XI(100),C(4,100),FXI(100),S(2)
          DATA N1/79/
          DATA((C(1,I),I=1,100)/2.785,2.628,2.492,2.368,2.257,2.156,2.065,
         11.982,1.908,1.841,1.780,1.725,1.675,1.629,1.587,1.549,1.514,
         21.482,1.452,1.424,1.399,1.375,1.353,1.333,1.314,1.296,1.279,
         31.264,1.248,1.234,1.221,1.209,1.197,1.186,1.175,1.156,1.138,
         41.122,1.107,1.093,1.081,1.069,1.058,1.048,1.039,1.030,1.022,
         51.014,1.007,.9994,.9932,.9870,.9811,.9755,.9700,.9649,.9600,
         6.9553,.9507,.9464,.9422,.9382,.9343,.9305,.9269,.8963,.8727,
         7.8538,.8379,.8242,.7432,.7005,.6718,.6504,.6335,.6194,.6076,
         8.5973,.5882,21*0./
          ITEST=0
          XI(1)=.3
          DO 10 I=2,35
       10 XI(I)=XI(I-1)+.05
          DO 20 I=36,65
       20 XI(I)=XI(I-1)+.1
          DO 30 I=66,70
       30 XI(I)=XI(I-1)+1.
          DO 90 I=71,79
       90 XI(I)=XI(I-1)+10.
          DO 40 I=1,N1
       40 FXI(I)=C(1,I)
          CALL ENDPTSL(XI,FXI,N1,S)
          C(2,1)=S(1)
          C(2,N1)=S(2)
          N=N1-1
          CALL SPLINE(N,XI,C)
          CALL CALCCF(N,XI,C)
          X=XI(1)
          DO 50 I=1,503
          FX=RCUBIC(X,N,XI,C)
          WRITE(6,60)I,X,FX
       60 FORMAT(1X,*PT.NO.=*I5,2X,*X=*E14.8,2X,*F(X)=*E14.8)
          IF(X.LT.4.35)GO TO 70
          IF(ITEST.EQ.1)GO TO 80
          X2=X-4.35
          IF(X2.LT..01)X=4.
          ITEST=1
       80 X=X+1.
          GO TO 50
       70 X=X+.01
       50 CONTINUE
          END

SUBROUTINE CALCCF       74/74    OPT=1                                 FTN 4.6+433B       06/18/79

          SUBROUTINE CALCCF(N,XI,C)
          DIMENSION XI(100),C(4,100)
          DO 10 I=1,N
          DX=XI(I+1)-XI(I)
          DIVDF1=(C(1,I+1)-C(1,I))/DX
          DIVDF3=C(2,I)+C(2,I+1)-2.*DIVDF1
          C(3,I)=(DIVDF1-C(2,I)-DIVDF3)/DX
       10 C(4,I)=DIVDF3/DX/DX
          RETURN
          END
```

```
SUBROUTINE ENDPTSL     74/74    OPT=1                                   FTN 4.6+433B        06/18/79

              SUBROUTINE ENDPTSL(XI,FXI,NK,S)
        C  CALCULATION OF SLOPE AT FIRST AND LAST POINT FOR SPLINE FIT USING LAGRANGIAN
        C  POLYNOMIALS
              DIMENSION XI(100),FXI(100),S(2)
              DO 30 I=1,2
              IF(I.NE.1)GO TO 10
              X=XI(1)
              K=4
              GO TO 20
           10 X=XI(NK)
              K=NK
           20 A0=X-XI(K-3)
              A1=X-XI(K-2)
              A2=X-XI(K-1)
              A3=X-XI(K)
              B0=XI(K-3)-XI(K-2)
              B1=XI(K-3)-XI(K-1)
              B2=XI(K-3)-XI(K)
              C1=XI(K-2)-XI(K-1)
              C2=XI(K-2)-XI(K)
              D1=XI(K-1)-XI(K)
              XLPR1=(A1*(A2+A3)+A2*A3)/(B0*B1*B2)
              XLPR2=(A0*(A2+A3)+A2*A3)/(-1.*B0*C1*C2)
              XLPR3=(A0*(A1+A3)+A1*A3)/(B1*C1*D1)
              XLPR4=(A0*(A1+A2)+A1*A2)/(-1.*B2*C2*D1)
           30 S(I)=FXI(K-3)*XLPR1+FXI(K-2)*XLPR2+FXI(K-1)*XLPR3+FXI(K)*XLPR4
              RETURN
              END


FUNCTION PCUBIC        74/74    OPT=1                                   FTN 4.6+433B        06/18/79

              FUNCTION PCUBIC(XBAR,N,XI,C)
              DIMENSION XI(100),C(4,100)
              DATA I/1/
              DX=XBAR-XI(I)
              IF(DX)10,30,20
           10 IF(I.EQ.1)GO TO 30
              I=I-1
              DX=XBAR-XI(I)
              IF(DX)10,30,30
           19 I=I+1
              DX=DDX
           20 IF(I.EQ.N)GO TO 30
              DDX=XBAR-XI(I+1)
              IF(DDX)30,19,19
           30 PCUBIC=C(1,I)+DX*(C(2,I)+DX*(C(3,I)+DX*C(4,I)))
              RETURN
              END
```

SUBROUTINE SPLINE 74/74 OPT=1 FTN 4.6+433B 06/18/79

```
      SUBROUTINE SPLINE(N,XI,C)
      DIMENSION XI(100),C(4,100),D(100),DIAG(100)
      DATA DIAG(1),D(1)/1.,0./
      NP1=N+1
      DO 10 M=2,NP1
      D(M)=XI(M)-XI(M-1)
   10 DIAG(M)=(C(1,M)-C(1,M-1))/D(M)
      DO 20 M=2,N
      C(2,M)=3.*(D(M)*DIAG(M+1)+D(M+1)*DIAG(M))
   20 DIAG(M)=2.*(D(M)+D(M+1))
      DO 30 M=2,N
      G=-D(M+1)/DIAG(M-1)
      DIAG(M)=DIAG(M)+G*D(M-1)
   30 C(2,M)=C(2,M)+G*C(2,M-1)
      NJ=NP1
      DO 40 M=2,N
      NJ=NJ-1
   40 C(2,NJ)=(C(2,NJ)-D(NJ)*C(2,NJ+1))/DIAG(NJ)
      RETURN
      END
```

APPENDIX B
PROGRAM LISTING FOR MUCALC - A ROUTINE TO CALCULATE THE MOLECULAR VISCOSITY OF NO_2 AND O_3 FROM 200 DEGREES K - 5000 DEGREES K

```
PROGRAM MUCALC      74/74   OPT=1          IXXXOEQ          FTN 4.6+433B       06/18/79

      PROGRAM MUCALC(OUTPUT,TAPE6=OUTPUT)
      DIMENSION XI(100),C(4,100),FXI(100),S(2)
      DATA N1/79/
      DATA(C(1,I),I=1,100)/2.785,2.628,2.492,2.368,2.257,2.156,2.065,
     11.982,1.908,1.841,1.780,1.725,1.675,1.624,1.587,1.549,1.514,
     21.482,1.452,1.424,1.399,1.375,1.353,1.333,1.314,1.296,1.279,
     31.264,1.248,1.234,1.221,1.209,1.197,1.186,1.175,1.156,1.138,
     41.122,1.107,1.093,1.081,1.069,1.058,1.048,1.039,1.030,1.022,
     51.014,1.007,.9999,.9932,.9870,.9811,.9755,.9700,.9649,.9600,
     6.9553,.9507,.9464,.9422,.9382,.9343,.9305,.9269,.8963,.8727,
     7.8538,.8379,.8242,.7432,.7005,.6718,.6504,.6335,.6194,.6076,
     8.5973,.5882,21*0./
      XI(1)=.3
      DO 10 I=2,35
   10 XI(I)=XI(I-1)+.05
      DO 20 I=36,65
   20 XI(I)=XI(I-1)+.1
      DO 30 I=66,70
   30 XI(I)=XI(I-1)+1.
      DO 90 I=71,79
   90 XI(I)=XI(I-1)+10.
      DO 40 I=1,N1
   40 FXI(I)=C(1,I)
      CALL ENDPTSL(XI,FXI,N1,S)
      C(2,1)=S(1)
      C(2,N1)=S(2)
      N=N1-1
      CALL SPLINEF(N,XI,C)
      CALL CALCCF(N,XI,C)
      DO 100 J=1,2
      IF (J.NE.1)GO TO 200
C     THIS SECTION CALCULATES MU(T) FOR O3
      EPSOK=206.4
      SIGMA=3.76
      XMW=48.000
      GO TO 300
C     THIS SECTION CALCULATES MU(T) FOR NO2
  200 EPSOK=331.8
      SIGMA=3.97
      XMW=46.008
  300 T=100.
      DELT=100.
      DO 400 I=1,49
      T=T+DELT
      X=T/EPSOK
      IF(X.GT.XI(N1).OR.X.LT.XI(1))GO TO 600
      OMEGAMU=PCUBIC(X,N,XI,C)
      XMU=2.6693E-5*SQRT(XMW*T)/(SIGMA*SIGMA*OMEGAMU)
      IF(I.EQ.1.AND.J.EQ.1)WRITE(6,800)
      IF(I.EQ.1.AND.J.EQ.2)WRITE(6,900)
  400 WRITE(6,700)T,XMU
  100 CONTINUE
      GO TO 1000
  600 WRITE(6,500)
  500 FORMAT(1X,*$$$$$$ ERROR$$$$$$-KT/EPS OUT OF RANGE OF TABLES $$$$$$
     1*)
  700 FORMAT(1X,*T=*F12.1,2X,*DEG K*,2X,*XMU=*E14.6,2X,*POISES*)
```


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```
  800 FORMAT(1H1,1X,*MOLECULAR VISCOSITY OF O3 AS A FUNCTION OF TEMPERAT
     1URE*///)
  900 FORMAT(1H1,1X,*MOLECULAR VISCOSITY OF NO2 AS A FUNCTION OF TEMPERA
     1TURE*///)
      CALL EXIT
 1000 STOP
      END
```

SUBROUTINE CALCCF - IDENTICAL TO CALCCF IN APPENDIX A

SUBROUTINE ENDPTSL - IDENTICAL TO ENDPTSL IN APPENDIX A

FUNCTION PCUBIC - IDENTICAL TO PCUBIC IN APPENDIX A

SUBROUTINE SPLINE - IDENTICAL TO SPLINE IN APPENDIX A

APPENDIX C
PROGRAM LISTING FOR MUCALC SPECIALIZED FOR CALCULATION OF THE MOLECULAR VISCOSITY OF CO_2

```
      PROGRAM MUCALC(OUTPUT,TAPE6=OUTPUT)
      DIMENSION XI(100),C(4,100),FXI(100),S(2)
      DATA N1/79/
      DATA(C(1,I),I=1,100)/2.785,2.628,2.492,2.368,2.257,2.156,2.065,
     11.962,1.906,1.841,1.780,1.725,1.675,1.629,1.587,1.549,1.514,
     21.462,1.452,1.424,1.399,1.375,1.353,1.333,1.314,1.296,1.279,
     31.264,1.248,1.234,1.221,1.209,1.197,1.186,1.175,1.156,1.138,
     41.122,1.107,1.093,1.081,1.069,1.058,1.048,1.039,1.030,1.022,
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     6.9553,.9507,.9464,.9422,.9382,.9343,.9305,.9269,.8963,.8727,
     7.8538,.8379,.8242,.7432,.7005,.6718,.6504,.6335,.6194,.6076,
     8.5973,.5882,21*0./
      XI(1)=.3
      DO 10 I=2,35
   10 XI(I)=XI(I-1)+.05
      DO 20 I=36,65
   20 XI(I)=XI(I-1)+.1
      DO 30 I=66,70
   30 XI(I)=XI(I-1)+1.
      DO 90 I=71,79
   90 XI(I)=XI(I-1)+10.
      DO 40 I=1,N1
   40 FXI(I)=C(1,I)
      CALL ENDPTSL(XI,FXI,N1,S)
      C(2,1)=S(1)
      C(2,N1)=S(2)
      N=N1-1
      CALL SPLINE(N,XI,C)
      CALL CALCCF(N,XI,C)
      DO 100 J=1,2
      IF (J.NE.1)GO TO 200
C   THIS SECTION CALCULATES MU(T) FOR O3
      EPSOK=206.4
      SIGMA=3.76
      XMW=48.000
      GO TO 300
C   THIS SECTION CALCULATES MU(T) FOR CO2
  200 EPSOK=190.
      SIGMA=3.996
      XMW=44.01
  300 T=100.
      DELT=100.
      DO 400 I=1,49
      T=T+DELT
      X=T/EPSOK
      IF(X.GT.XI(N1).OR.X.LT.XI(1))GO TO 600
      OMEGAMU=PCUBIC(X,N,XI,C)
      XMU=2.6693E-5*SQRT(XMW*T)/(SIGMA*SIGMA*OMEGAMU)
      IF(I.EQ.1.AND.J.EQ.1)WRITE(6,800)
      IF(I.EQ.1.AND.J.EQ.2)WRITE(6,900)
  400 WRITE(6,700)T,XMU
  100 CONTINUE
      GO TO 1000
  600 WRITE(6,500)
  500 FORMAT(1X,*$$$$$$ ERROR$$$$$$-KT/EPS OUT OF RANGE OF TABLES $$$$$$
     1*)
  700 FORMAT(1X,*T=*F12.1,2X,*DEG K*,2X,*XMU=*E14.6,2X,*POISES*)
```


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PROGRAM MUCALC 74/74 OPT=1 IXXXO1V FTN 4.6+433B 06/18/79

```
 600 FORMAT(1H1,1X,*MOLECULAR VISCOSITY OF O3 AS A FUNCTION OF TEMPERAT
    1URE*///)
 900 FORMAT(1H1,1X,*MOLECULAR VISCOSITY OF CO2 AS A FUNCTION OF TEMPERA
    1TURE*///)
     CALL EXIT
1000 STOP
     END
```

SUBROUTINE CALCCF - IDENTICAL TO CALCCF IN APPENDIX A

SUBROUTINE ENDPTSL - IDENTICAL TO ENDPTSL IN APPENDIX A

FUNCTION PCUBIC - IDENTICAL TO PCUBIC IN APPENDIX A

SUBROUTINE SPLINE - IDENTICAL TO SPLINE IN APPENDIX A

APPENDIX D
PROGRAM LISITNG FOR MUSPEC - A ROUTINE WHICH CALCULATES $\mu = \mu_i(T)$ FOR N_2, O_2, NO_2, NO, AND O_3 AT TEMPERATURES BETWEEN 200 DEGREES K AND 1000 DEGREES K

```
PROGRAM MUSPEC      74/74    OPT=1           WJWDK4N            FTN 4.6+439          06/19/79

          PROGRAM MUSPEC(OUTPUT,TAPE6=OUTPUT)
          DIMENSION C(4,9),XI(9),S(2),C1(9,5),FXI(9),C2(4,9,5)
          DATA(C1(I,1),I=1,9)/131.3,177.7,217.2,252.7,285.4,315.6,
         1344.0,371.0,397.1/
          DATA(C1(I,2),I=1,9)/147.9,206.4,256.5,301.0,341.4,379.1,
         1414.8,448.5,480.6/
          DATA(C1(I,3),I=1,9)/136.5,192.0,239.7,282.0,320.5,356.2,
         1389.9,421.9,452.4/
          DATA(C1(I,4),I=1,9)/78.9,119.1,158.6,195.9,230.8,263.3,
         1293.9,322.8,350.1/
          DATA(C1(I,5),I=1,9)/114.7,170.1,220.1,265.0,305.9,343.5,
         1378.6,412.0,443.6/
          N1=9
          N=N1-1
          XI(1)=200.
          DO 10 I=2,9
       10 XI(I)=XI(I-1)+100.
          DO 20 I=1,5
          DO 30 J=1,N1
          C(1,J)=C1(J,I)
       30 FXI(J)=C(1,J)
          CALL ENDPTSL(XI,FXI,N1,S)
          C(2,1)=S(1)
          C(2,N1)=S(2)
          CALL SPLINE(N,XI,C)
          CALL CALCCF(N,XI,C)
          DO 40 L=1,4
          DO 40 J=1,9
       40 C2(L,J,I)=C(L,J)
       20 CONTINUE
          DELX=10.
          X=500.
          DO 80 L=1,10
          DO 50 K=1,5
          DO 60 I=1,4
          DO 60 J=1,9
       60 C(I,J)=C2(I,J,K)
          XMU=PCUBIC(X,N,XI,C)
       50 WRITE(6,70)K,XMU,X
       70 FORMAT(1X,*MU(*,I1,*)=*E14.8,2X,*AT T=*F10.1,*DEG K*)
          WRITE(6,90)
       90 FORMAT(1X,//)
       80 X=X+DELX
          STOP
          END
```

SUBROUTINE CALCCF - IDENTICAL TO CALCCF IN APPENDIX A

SUBROUTINE ENDPTSL - IDENTICAL TO ENDPTSL IN APPENDIX A

FUNCTION PCUBIC - IDENTICAL TO PCUBIC IN APPENDIX A

SUBROUTINE SPLINE - IDENTICAL TO SPLINE IN APPENDIX A

APPENDIX E
PROGRAM LISTING FOR LVSCTST - A ROUTINE TO CALCULATE $\mu_{MIX} = \mu_{MIX}(T)$ FOR MIXTURES OF N_2, O_2, NO, NO_2, AND O_3

```
PROGRAM LVSCTST     74/74    OPT=1           WJWDK45            FTN 4.6+439          06/20/79

            PROGRAM LVSCTST(OUTPUT,TAPE6=OUTPUT)
      C   PROGRAM TO CHECK OUT SUBROUTINE LAMVISC WHICH CALCULATES THE MOLECULAR
      C   VISCOSITY OF A MIXTURE OF GASES AS A FUNCTION OF TEMPERATURE
            DIMENSION WTMOLE(25),XMUL(5),ALPHA(25,50),T(50)
            COMMON/LVISC/T,WTMOLE,ALPHA
            DATA(WTMOLE(I),I=1,5)/28.02,32.00,30.01,46.008,48.00/
            DATA(T(I),I=1,6)/300.,305.,350.,400.,500.,525./
            DATA((ALPHA(J,I),J=1,5),I=1,6)/.7,.3,0.,0.,0.,
           1.7,.05,.15,.05,.05,  .7,.1,.1,.05,.05,  .6,.1,.05,.2,.05,
           2.6,.1,.1,.1,.1,  .6,.05,.05,.2,.1/
      C   SAMPLE INPUT DATA
            NS=5
            WTVR=1.
            MPSI=6
      C   END OF SAMPLE DATA
            DO 40 K=1,2
            CALL LAMVISC(NS,MPSI,WTVR,XMUL)
            DO 10 I=1,6
            WRITE(6,20)ALPHA(1,I),ALPHA(2,I),ALPHA(3,I),ALPHA(4,I),ALPHA(5,I)
         20 FORMAT(1X,//*FOR THE FOLLOWING GAS MIXTURE -N2=*F6.3,1X,
           1*O2=*F6.3,1X,*NO=*F6.3,1X,*NO2=*F6.3,1X,*O3=*F6.3)
            WRITE(6,30)XMUL(I),T(I)
         30 FORMAT(1X,*MUMIX=*E14.8,2X,*AT T=*E14.8//)
         10 CONTINUE
         40 CONTINUE
            STOP
            END
```

```
SUBROUTINE LAMVISC    74/74    OPT=1           WJWDK45            FTN 4.6+439          06/20/79

            SUBROUTINE LAMVISC(NS,MPSI,WTVR,XMUL)
            DIMENSION XMUL(50),XMF(25,50),T(50),WTMOLE(25),ALPHA(25,50),
           1XMU(5),PHI(25,25)
            COMMON/LVISC/T,WTMOLE,ALPHA
            NT=9
            DO 30 K=1,MPSI
            XMUL(K)=0.
            DO 20 I=1,NS
            DO 40 J=1,NS
         40 XMF(J,K)=ALPHA(J,K)*WTVR
            CALL MUSEFC(NT,NS,T(K),XMU)
            SUMD=0.
            DO 10 J=1,NS
            PHI(I,J)=1./SQRT(8.)*(1.+WTMOLE(I)/WTMOLE(J))**(-.5)*
           1(1.+SQRT(XMU(I)/XMU(J))*(WTMOLE(J)/WTMOLE(I))**.25)**2
         10 SUMD=SUMD+XMF(J)*PHI(I,J)
            XNUM=XMF(I)*XMU(I)/SUMD
         20 XMUL(K)=XMUL(K)+XNUM
         30 CONTINUE
            RETURN
            END
```


[redacted]

```
      SUBROUTINE MUSPEC(NT,NS,T,XMU)
      DIMENSION C(4,9),XI(9),S(2),C1(9,5),FXI(9),C2(4,9,5),XMU(5)
      DATA(C1(I,1),I=1,9)/131.3,177.7,217.2,252.7,285.4,315.6,
     1344.0,371.0,397.1/
      DATA(C1(I,2),I=1,9)/147.9,206.4,256.5,301.0,341.4,379.1,
     1414.8,448.5,480.6/
      DATA(C1(I,3),I=1,9)/136.5,192.0,239.7,282.0,320.5,356.2,
     1389.9,421.5,452.4/
      DATA(C1(I,4),I=1,9)/78.9,119.1,158.6,195.9,230.8,263.3,
     1293.9,322.8,350.1/
      DATA(C1(I,5),I=1,9)/114.7,170.1,220.1,265.0,305.9,343.5,
     1378.6,412.0,443.6/
      DATA NCNT/0/
      IF(NCNT.EQ.1)GO TO 100
      N1=NT
      N=N1-1
      XI(1)=200.
      DO 10 I=2,NT
   10 XI(I)=XI(I-1)+100.
      DO 20 I=1,NS
      DO 30 J=1,N1
      C(1,J)=C1(J,I)
   30 FXI(J)=C(1,J)
      CALL ENDPTSL(XI,FXI,N1,S)
      C(2,1)=S(1)
      C(2,N1)=S(2)
      CALL SPLINE(N,XI,C)
      CALL CALCCF(N,XI,C)
      DO 40 L=1,4
      DO 40 J=1,9
   40 C2(L,J,I)=C(L,J)
   20 CONTINUE
      NCNT=1
  100 CONTINUE
      DO 60 K=1,NS
      DO 60 I=1,4
      DO 60 J=1,NT
      C(I,J)=C2(I,J,K)
   60 XMU(K)=PCUBIC(T,N,XI,C)
      RETURN
      END
```

SUBROUTINE CALCCF - IDENTICAL TO CALCCF IN APPENDIX A

SUBROUTINE ENDPTSL - IDENTICAL TO ENDPTSL IN APPENDIX A

FUNCTION PCUBIC - IDENTICAL TO PCUBIC IN APPENDIX A

SUBROUTINE SPLINE - IDENTICAL TO SPLINE IN APPENDIX A

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2. Svehla, Roger A., "Estimated Viscosities and Thermal Conductivities of Gases at High Temperatures" NASA Technical Report R-132, Lewis Research Center, Cleveland, Ohio, 1962.

3. Bird, R.B., Stewart, W.E. and E.N. Lightfoot, *Transport Phenomena*, John Wiley, New York, 1960.

4. Walker, B.J., "Turbulence Model Comparisons for Shear Layers and Axisymmetric Jets" MICOM Technical Report TR-RD-80-1, Redstone Arsenal, Alabama, October 1979.

SYMBOLS

Ω_{μ} -	Viscosity potential function of $(\kappa T/\epsilon)$
ϵ -	Characteristic energy of interaction between molecules, erg/molecule
r -	Intermolecular distance, cm
σ -	Collision diameter of a molecule, Å
T_c -	Critical temperature, degrees K
p_c -	Critical pressure, atm
V_c -	Critical volume, gm/gm-mole
κ -	Boltzman constant, 1.3805 erg/molecule-degrees K
$\phi(r)$ -	Lennard-Jones potential, Equation (14)
MW_i -	Molecular weight, i^{th} specie, gm/gm-mole
μ_i -	Molecular viscosity, i^{th} specie, poise
x_i -	Mole fraction, i^{th} specie, dimensionless
Φ_{ij} -	Viscosity weighting function, Equation (2)

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